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Jet Aircraft Engine Emissions Database Development—1992 Military, Charter, and Nonscheduled Traffic

Munir Metwally

Contract NAS1-19345
Prepared for Langley Research Center

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ACRONYMS

AESA	Atmospheric Effects of Stratospheric Aircraft
ASK	Available seat kilometers
BCAG	Boeing Commercial Aircraft Group
CIS	Commonwealth of Independent States
CO	Carbon monoxide
AESA	Atmospheric Effects of Stratospheric Aircraft
EI	Emission index
HC	Unburned hydrocarbons
HSCT	High speed civil transport
ICAO	International Civil Aviation Organization
LRC	Langley Research Center
MDC	McDonnell Douglas Corporation
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NO_x	Nitrogen oxides
PAA	Primary Aircraft Authorization
RPK	Revenue passenger kilometers
SASS	Subsonic Assessment
US	United States

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INTRODUCTION

Jet aircraft operations in the Earth's atmosphere and the resultant engine exhaust emissions continue to receive significant worldwide interest from industry, government, academia, and environmental groups. A large part of this interest is due to studies showing that the release of manmade aerosols or gases at the Earth's surface or injection at altitude may affect the concentration of naturally occurring gases, e.g. ozone, in the atmosphere. The exact nature of the reactions that occur as a result of these emissions, the local and global impacts, and the temporal and long-term consequences of these releases are still uncertain.

The effects of jet aircraft engine exhaust emissions on atmospheric chemical and/or physical processes, e.g. ozone formation, global warming, and acid rain, are not necessarily homogeneous and are not yet fully understood, but the altitude at which the emissions are injected is known to be an influential factor. Although aircraft engine exhaust emissions, and in particular nitrogen oxides (NO_x), are a small fraction of total global emissions (less than 3% for NO_x), the preponderance of these emissions occur at high altitudes (Bahr, 1992, Ref. 1).

McDonnell Douglas Corporation's (MDC) prior participation in the National Aeronautics and Space Administration's (NASA) Subsonic Assessment (SASS) investigation has included developing jet aircraft engine exhaust emissions databases for the year 1990 and a forecast for the year 2015 (NASA Contractor Report 4613, Ref. 2). MDC's current participation, and the subject of this report, is the development of the 1992 database. These databases form an integral part of both subsonic atmospheric assessment, and the HSCT atmospheric impact assessment being performed by NASA's Atmospheric Effect of Stratospheric Aircraft (AESA). Each database represents one component of jet aircraft operations or services and consists of a global, three-dimensional grid, one degree latitude by one degree longitude by one kilometer altitude. The grid's cells contain aggregate estimates of the annualized fuel burn and levels of engine exhaust emission constituents, specifically NO_x, carbon monoxide (CO), and unburned hydrocarbons (HC), produced by jet aircraft operating in the cell. MDC investigated military, charter, and unreported domestic traffic jet aircraft operations (Barr, et al., 1993, Ref. 3). Unreported domestic traffic refers to the Commonwealth of Independent States (CIS), Chinese, and Eastern European domestic air traffic services not reported in the Official Airline Guide (OAG, 1992, Ref. 4).

This report addresses the MDC effort to develop the databases for the military, charter, and unreported domestic traffic for the year 1992. The remainder of this report is organized as follows. First, the database development process is outlined, including the steps necessary to construct the grids. Next, the nature of jet aircraft engine exhaust emissions and definition of emission indices are presented. Then, aspects of the military, charter, and unreported domestic traffic database development efforts for the 1992 scenario is provided. The summary examines the emissions level variance between the 1992 and 1990 scenarios.

ENGINE EXHAUST EMISSIONS DATABASE DEVELOPMENT PROCESS

Ideally, all information necessary to construct an accurate emissions grid for any aircraft operations component is readily available. This is seldom the case, and data scarcity may require simplifying assumptions which may have an impact on the overall level of accuracy. These assumptions are noted where appropriate.

First, an inventory of the types and quantities of operational aircraft in use for a specific *mission* is established or forecast. Here *mission* is used in a general context that has applicability to both military and commercial aircraft operations, and it refers to how aircraft are employed. Aircraft in the inventory are characterized in terms of design mission(s), configuration, engine type and quantity, and weights.

Second, engine characteristics, including thrust rating and fuel consumption rate, are defined for each unique engine in the aircraft inventory. Several different aircraft may use the same type of engine. The engine and aircraft characteristic data together establish the performance capabilities.

Third, to describe the aircraft operations network, a flight route or profile is defined by specifying the origin, destination, navigation points (where the aircraft changes course), altitude/speed change points, and flight frequency, and an aircraft is assigned to the specified route. Each route consists of one or more great circle flight segments. Flight frequency, or utilization, is measured either by flight hours or trips per year. The commercial air traffic (revenue passenger kilometers or available seat kilometers) or the military operating tempo postulated for the network and aircraft capacity, range, and operating characteristics all can influence the flight frequency.

Prior to describing the grid generation process, the generic aircraft approach used by MDC for the SASS investigation and the nature of jet aircraft engine exhaust emissions are presented.

Generic Aircraft

The military, charter, and unreported domestic traffic aircraft operations components utilized many unique aircraft designs and derivatives, numbering in the hundreds, during 1992. The component inventories include a wide variety of aircraft, ranging from high-technology, front-line fighter aircraft with state-of-the-art propulsion systems to 1940's vintage transports equipped with radial engines. Developing realistic fuel consumption and engine exhaust emission estimates for so many different aircraft types is impossible without detailed performance data on each aircraft type. Therefore, to reduce the problem to a manageable size, MDC used *generic aircraft* to develop the emissions databases for the 1992 scenario.

Specifically, one or more notional aircraft were used to represent all aircraft in a component's inventory that perform a particular mission. A component's generic aircraft are composites of the characteristics of the actual aircraft performing the missions and are, in fact, real aircraft (for

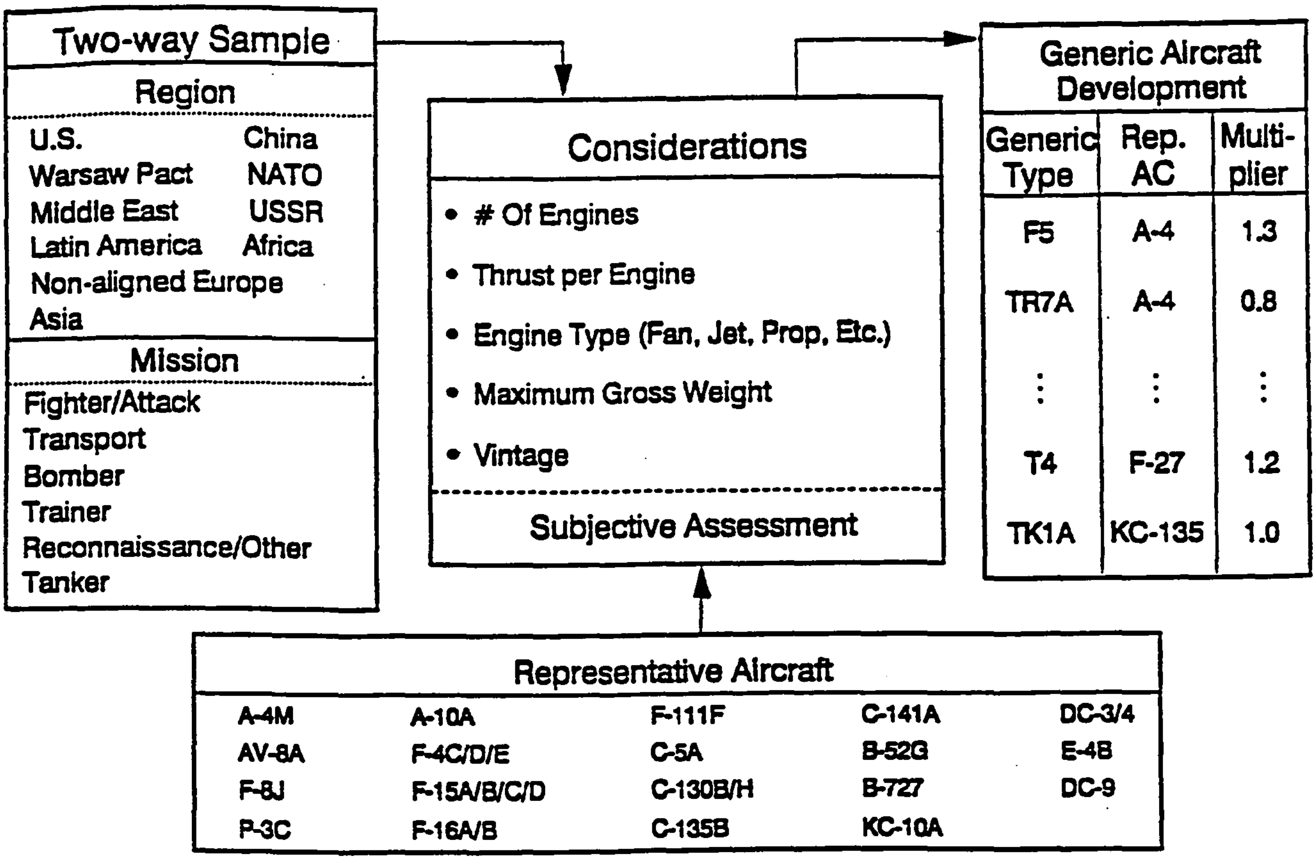


Figure 1. The military component generic aircraft development process. The charter and unreported, domestic traffic components used a similar, but less detailed, approach.

which accurate performance data are available) assigned fuel burn multipliers. A fuel burn multiplier is a weighted-average function, applied by mission category, of aircraft maximum gross weight, engine quantity, rated thrust, and thrust specific fuel consumption. The desired performance of the generic aircraft is approximated by the product of the fuel burn multiplier and the real aircraft's fuel consumption rates. Other characteristics considered in developing the generic aircraft included wing configuration, performance (range and capacity), and vintage. Figure 1 shows the generic aircraft development process for the military component. This process is largely subjective and limited by the availability of real aircraft performance data. Finally, a generic aircraft's engine exhaust emission indices are assumed to be equal to the engine exhaust emission indices of the real aircraft upon which the generic aircraft is based. Additional details on a specific component's generic aircraft are provided in the applicable section below.

Engine Exhaust Emissions

An engine EI measures the mass of exhaust constituent produced per mass of fuel consumed and is typically depicted as a function of engine power setting or fuel flow rate. The relative concentrations of exhaust constituents vary over the flight profile. Carbon dioxide and water vapor are the primary constituents for commercial jet aircraft; NO_x, CO, HC, sulfur dioxide, and

Table 1. Exhaust Emission Indices for the Pratt & Whitney JT8D-15 Turbofan Engine[a]

Power Setting	Fuel Flow (kg/hr)	Emission Indices (g/kg)		
		NO_X[b]	CO	HC
Takeoff	4241	19.1	0.7	0.3
Climb Out	3402	15.0	1.0	0.3
Approach	1225	5.9	9.6	1.7
Cruise	1588	7.4	8.1	1.5
Idle	532	3.0	35.6	11.0

(a) ICAO, 1989.

[b] NO_X emission index in g of NO_X as NO_2 emitted per kg of fuel.

smoke are also present. The emission indices measure the combustor cleanliness for a given engine cycle. As an example, Table 1 presents the emission indices for the Pratt & Whitney JT8D-15 mixed flow turbofan engine.

Substantial previous work (Pace, 1977, Ref. 5; Sears, 1978 Ref. 6; ICAO, 1989, Ref. 7) has been accomplished to document emission indices for a wide variety of commercial and military jet engines. Because earlier work focused on emissions levels in proximity to airports, much of the reported data is limited to engine power settings common to the landing-takeoff cycle, i.e. taxi/idle, takeoff, climb, and approach. Therefore, linear interpolation has been used when necessary during the grid generation to derive emission indices at power settings or fuel flow rates between reported values. Table 1 presents the result of the interpolation technique for deriving the cruise emission indices. Also, the indices have been stratified into one kilometer altitude bands by weight averaging calculated engine fuel flows in the band. Emissions indices for a specific engine were assumed to be independent of the aircraft installation and altitude. Effects of altitude on emission indices were incorporated using a methodology that correlates indices with fuel flowrate and atmospheric conditions (Martin, 1993, Ref. 8).

CO and HC

Emissions of CO and HC are largely the result of incomplete combustion. CO and HC emissions contribute to local CO and smog concentrations, respectively (Bahr, 1992, Ref. 1). For a specific engine application, EI(CO) and EI(HC) decrease as a function of engine power settings with different rated thrusts. Thus, CO and HC emissions predominate at idle and other low engine power settings. Moreover, for a given engine power setting, EI(CO) and EI(HC) tend to decrease as engine rated thrust increases for modem day production engines. This tendency is likely due to pressure ratio, surface-to-volume ratio, and air loading scale effects (Munt and Danielson, 1976, Ref. 9).

NO_X

NO_X emissions occur primarily at high engine power settings and during the cruise portion of flight and are the result of high combustion temperatures. $EI(NO_X)$ is highest for subsonic aircraft during the takeoff phase of flight. For a given engine, $EI(NO_X)$ increases with power setting and EI(NO_x) for modern production engines increases with rated thrust. In fact, EI(NO_x) correlates very well with combustor inlet temperature (Munt and Danielson, 1976, Ref. 9).

Jet aircraft engine CO and HC exhaust emissions at low altitudes contribute only marginally to total local CO and HC levels, but NO_x aircraft emissions, released predominantly at high altitudes, constitute a relatively larger proportion of the local NO_x levels. At present, there is considerable uncertainty with regards to the complex chemical reactions involving NO_x emissions at high altitudes. NO_x emissions in the upper troposphere and lower stratosphere, where current subsonic aircraft cruise, may lead to ozone formation and consequently contribute to global warming. However, NO_x releases at these altitudes may also reduce the residence time of other gases that contribute to global warming.

Grid Generation

Generating the grid is a two-step process that first allocates fuel consumption estimates to individual grid cells and subsequently multiplies the fuel burn estimate by the appropriate emission index.

Annual fuel consumption estimates are resolved into a global three-dimensional grid, one degree latitude by one degree longitude by one kilometer altitude, for each unique route/aircraft combination after summarizing the mission profile into a position, distance, time, fuel, and altitude data set. Table 2 shows an example of a data set, consisting of eight flight segments, for a generic attack aircraft flying a typical combat mission with some low level operations. For other generic aircraft types (i.e bomber, transports), with different flight profiles, fuel/altitude schedules would have different representations. Each great circle flight segment traverses one or more grid cells. The fuel consumed on any flight segment is linearly allocated in both geographic position and altitude, by distance, to the grid cells the segment traverses.

Next, each active grid cell's fuel burn estimate (a grid element is active if its fuel burn figure is positive) is supplemented with estimates of engine exhaust emissions levels by multiplying the fuel burn estimate by the appropriate constituent EI. The grid generation process occurs for each unique aircraft represented in the component. The resultant grids are then summed by cell to produce an aggregate grid. This aggregate grid is the component's emission database.

MILITARY AIRCRAFT OPERATIONS COMPONENT EMISSIONS

This section discusses the development of the military component emissions databases for the 1992 using the 1990 scenario as a baseline. In addition to the final database consisting of estimates of fuel burn and exhaust constituent levels, supporting databases include inventories of military aircraft, basing locations, generic aircraft and associated mission profiles, engine emission indices, and flight frequencies.

Table 2. Sample Flight Position, Distance, Time, Fuel Burn, and Altitude Data Set

			Cumulative		
Latitude	Longitude	Distance (km)	Time (hr)	Fuel Burn[a] (kg)	Altitude (km)
30°0'N	90°0'W	0	0	0	0
30°2'N	90°4'W	9	0.1	1905	0.5
30°18'N	90°37'W	69	1.2	8618	7.6
32°10'N	94°36'W	500	0.8	24,312	7.6
32°24'N	95°7'W	556	0.9	24,730	1.5
32°24'N	95°7'W	556	1.5	46,266	1.5
32°6'N	94°27'W	626	1.6	51,437	11.4
30°31'N	91°4'W	993	2.1	59,602	11.7
30°0'N	90°0'W	1111	2.7	67,857	0

[a] Cumulative annual fuel burn based on 20 missions per year.

Inventory of Military Aircraft

The military component inventories include only those aircraft, excluding helicopters, with the potential to release jet engine exhaust emissions at substantially high altitudes. The totals include aircraft assets from all branches of the military as well guard, reserve, and paramilitary forces where applicable. The inventories are categorized by mission, country, and region.

Some military aircraft can perform multiple missions. For the purpose of developing generic aircraft, similar missions were combined. The five mission categories are fighter/attack, transport, bomber, trainer, and (miscellaneous) other. The fighter/attack mission category includes those aircraft whose primary mission role is air-to-air combat and/or ground attack and air defense. Aircraft used in strategic and tactical transport, liaison, executive transport, or aeromedical evacuation roles compose the transport mission category. The transport mission category also includes aerial refueling (tanker) aircraft except for the United States (US) and CIS in which case the aerial refueling mission is a separate category. The bomber mission category includes both long-range and short-range bombers. The miscellaneous other category contains maritime patrol; airborne electronic platforms performing electronic warfare, electronic intelligence, and electronic countermeasures missions; reconnaissance and surveillance; and special operations aircraft.

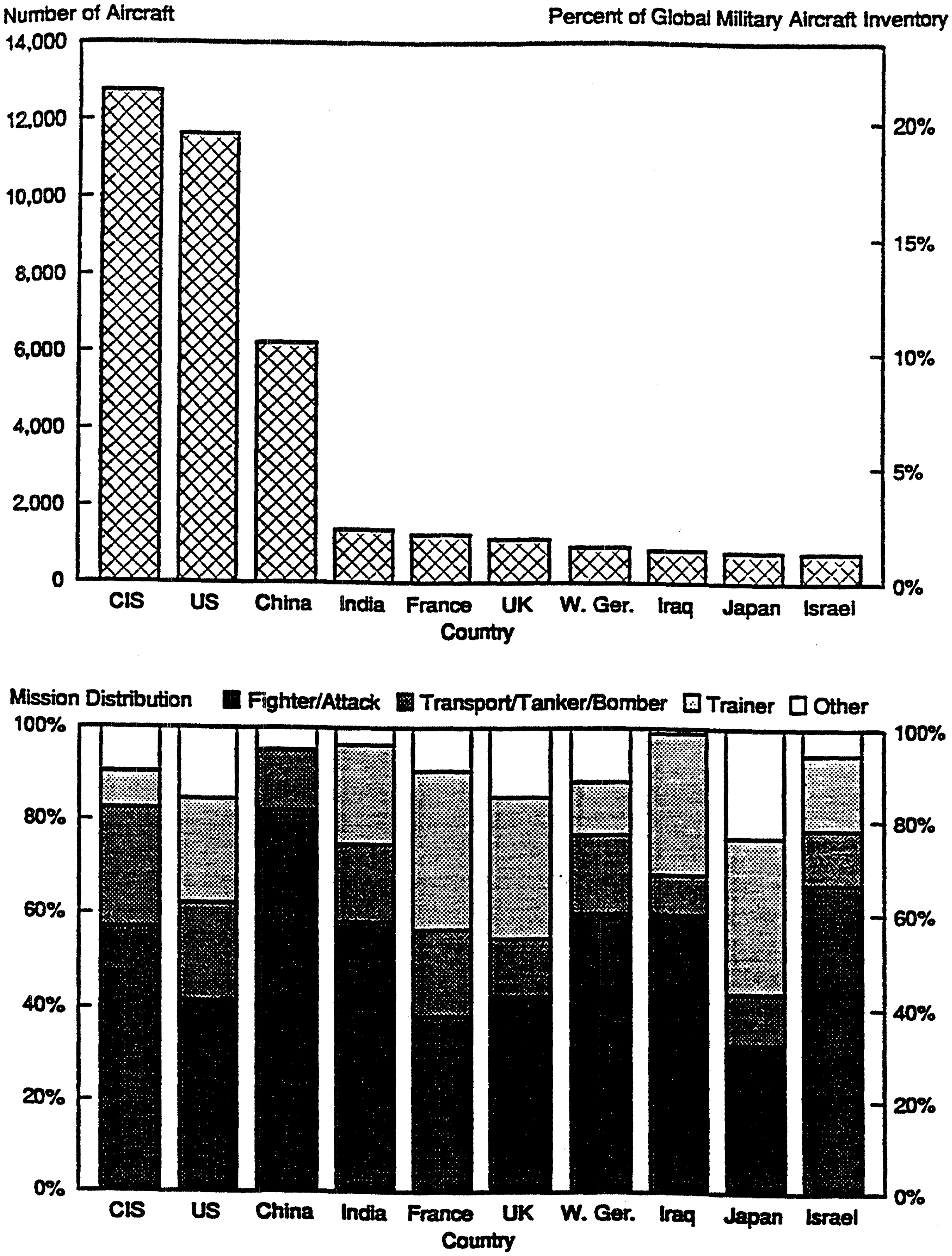


Figure 2. Distribution of 1992 military aircraft. Upper panel shows total aircraft possessed by top ten countries. Bottom panel shows distribution of aircraft by mission type.

In 1992, 138 countries owned approximately 52,000 fixed-wing military aircraft (Air Force, 1992, Ref. 10; International Institute for Strategic Studies, 1991, Ref. 11; International Media Corporation, 1990, Ref. 12). Together, the US, CIS, and China accounted for over 50% of the total fleet. Table 3 summarizes the 1992 inventory of military aircraft, and Figure 4 shows the distribution of aircraft among the top countries in terms of numbers of aircraft. The full inventory of 1992 military aircraft, by country, is at Appendix A.

Table 3. 1992 Inventory of Military Aircraft(a)

	Mission						
	Fighter/ Attack	Transport(b)	Bomber	Trainer	Other	Total	Percent
CIS	4565	1707	751	1000	646	8,669	16.7%
US	5000	2006	312	2198	1766	11,282	21.7%
Asia/Australasia	3456	939	90	1157	514	6,156	11.9%
NATO	3325	1227	18	1602	694	6,866	13.2%
China(c)	5200	218	630	0	310	6,358	12.3%
Middle East/North Africa	3155	604	11	1044	152	4,966	9.6%
Caribbean/Latin America	1104	810	6	837	165	2,922	5.6%
Warsaw Pact	1891	207	0	328	137	1,654	3.2%
Sub-Sahara Africa	745	408	0	215	113	1,481	2.9%
Non-Aligned Europe	1118	69	0	205	154	1,546	3.0%
Global Total	28,677	8,107	1,818	8,612	4,686	51,900	100%
Mission Distribution	55.3%	15.6%	3.5%	16.6%	9.0%	100%	

(a) All numbers are approximate.
(b) Aerial refueling (tanker) aircraft included in the transport category: CIS, 74; US, 798; NATO, 69.
(c) China's trainer aircraft quantity is unknown and may be included in the reported fighter/attack aircraft numbers.

Military Generic Aircraft

Appendix A identifies the generic aircraft used in the 1992 scenario. In some cases, a region, alliance, or country group shows multiple generic aircraft for a single mission category because of the diversity of aircraft in the inventory. For example, there are two generic transport aircraft, one short-range and one long-range, used in the Middle East/North Africa region. The short-range generic aircraft represents 86% of all Middle East/North Africa transport aircraft; the long-range generic aircraft represents the balance.

Aircraft Basing

Several options are available for locating, or basing, military aircraft. Where an aircraft is located is important because all missions originate from the base, hence exhaust emissions will tend to concentrate at the base locations. The most accurate approach with respect to emissions levels is to base aircraft at their actual operating locations and subsequently operate the aircraft from these locations to their actual destinations. This approach requires a substantial amount of military operations data be available to match military aircraft inventories with operating locations. The accuracy gained by adopting this approach may be limited by the impreciseness of other factors, especially mission routing, inventory levels, and utilization rates.

A less exacting alternative is to base all of a region/alliance/country group's military aircraft at a single location within the political boundaries of the group. This approach, while not requiring the detailed information of the first approach, suffers when the group is physically large because of the database grid element resolution (one-degree latitude by one-degree longitude by one-kilometer altitude).

Central Basing

MDC adopted a central basing approach for the 1992 scenario which combined the two basing alternative extremes described above. With the exception of the US, CIS, and China, all of a country's military aircraft were based at one or two centrally located airfields within the political boundaries of the country (DMA, 1991, Ref. 13). Those aircraft deployed to a foreign territory were based in the host country. Appendix A contains the geographic coordinates of the selected central basing locations as well as the US, CIS, and China bases used to station their generic aircraft.

CIS

Twenty-one percent of the world's military aircraft are owned by the CIS. The sizes of the CIS military aircraft fleet and the CIS landmass suggest a more accurate estimate of the CIS's contribution to engine exhaust emissions would be obtained by basing its aircraft in a more representative fashion than the central basing concept described above.

In 1992, the former Soviet Union located its military assets among eight entities called fleets, front, or strategic directions (International Institute for Strategic Studies, 1991, Ref. 11). These include the Northern Fleet, Northern Front, Western Strategic Direction, Southwestern Strategic Direction, Southern Strategic Direction, Central Strategic Region, Far Eastern Strategic Direction, and the Pacific Fleet. With the exception of the Northern Fleet and the Pacific Fleet, each entity was further divided into military districts (within the former Soviet Union) and groups of forces. The groups of forces represent CIS forces stationed in Warsaw Pact countries. While aviation assets may be dispersed, central control is maintained over much of the strategic forces. Aircraft in the CIS inventory were allocated, by mission type, to the eight entities approximately in proportion to the actual basing of military aircraft. Then, a single, central location within each entity was selected to be the base from which all missions would originate. Aircraft representing strategic aviation assets not specifically assigned to a strategic direction were evenly dispersed among the entities.

US

The US operates the world's second largest fleet of military aircraft, accounting for approximately 19% of the global total. For basing purposes, the US was subdivided into five regions and one or more locations selected within each region to station the generic aircraft as shown in Figure 3. Each region's allocation of aircraft, by mission type, approximates the actual mix of operational aircraft assigned to military bases contained in the region (Air Force, 1992, Ref. 10; MILAV News, 1991, Ref. 14). Some US Air Force and Navy aircraft were located in foreign territories to reflect unit deployments.

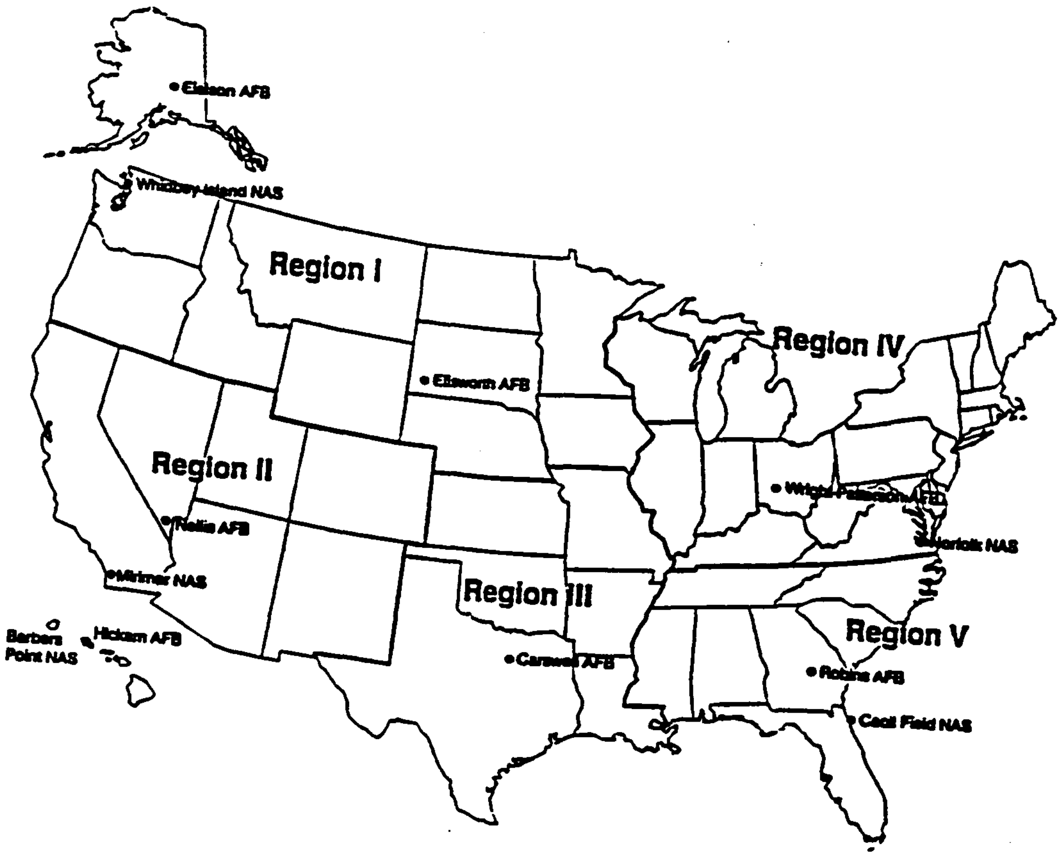


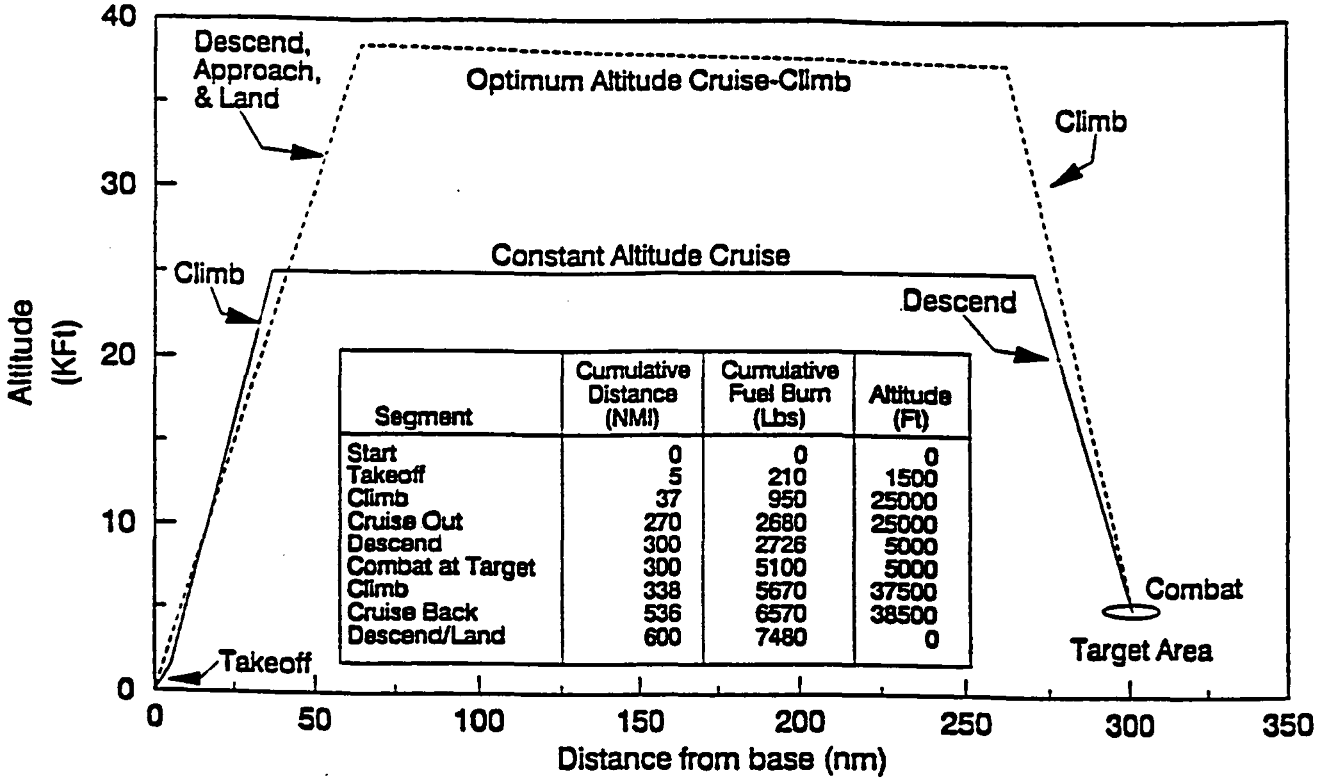
Figure 3. Generic aircraft representing the US fleet were based at several Air Force and Navy facilities. The allocation of aircraft was based on the distribution of military forces among the regions.

China

With roughly 10% of the world's military aircraft, China's fleet is largely based on variants of dated Soviet designs. Similar to the CIS, China has military regions and is further subdivided into military districts. Unclassified information on China's military structure, unit size, basing, and assets is scarce and typically couched in uncertainties. Ten military regions were assumed and air divisions comprising bomber, fighter/attack, transport, and other aircraft were assigned to the regions. Regions bordering the CIS and the costal regions near Taiwan received a greater share of air divisions. As in the CIS case above, a single, central location within each region was selected to station the air divisions. Generic aircraft representing China's naval aviation assets were equally divided among the North Sea Fleet, East Sea Fleet, and South Sea Fleet and based at a single shore facility within each fleet's operating area.

Mission Profiles

The US Air Force has established standard mission profiles for a wide variety of aircraft and missions (USAF, 1977, 1989a, Ref. 15,16). These profiles have been adapted for this analysis. A generic aircraft's mission includes takeoff from the origin, an initial climb to cruise altitude, a fixed distance cruise segment along a great circle route, and, depending on the mission type,



Segment	Cumulative Distance (NMI)	Cumulative Fuel Burn (Lbs)	Altitude (Ft)
Start	0	0	0
Takeoff	5	210	1500
Climb	37	950	25000
Cruise Out	270	2680	25000
Descend	300	2726	5000
Combat at Target	300	5100	5000
Climb	338	5670	37500
Cruise Back	536	6570	38500
Descend/Land	600	7480	0

Figure 4. Example mission profile for a fighter/attack generic aircraft. All military air traffic component missions begin and end at the same location.

either a landing and subsequent return to the origin, a period of combat training maneuvers and subsequent return to the origin, or an immediate return to the origin. All military air traffic component missions begin and end at the same location. Figure 4 illustrates a typical mission profile for a fighter/attack aircraft. For each generic aircraft type, the mission profile is numerically summarized by a position; cumulative distance, time, and fuel burn; and altitude data set, an example of which is shown in Table 2.

At least three randomized headings, indicating the initial flight direction from the origin, were generated for each generic aircraft type. Where feasible, the allowable headings were restricted so flights occurred as much as possible over a group's own territory.

Utilization

The last data required to estimate the military air traffic component's contribution to global fuel burn and exhaust emission levels is aircraft utilization (flight hours per year) for each mission category in a region/alliance/country group. For the purpose of this study, aircraft utilization rates were scaled off historical US Air Force planning factors.

At some point during the course of a year, a military aircraft may be considered nonoperational. In the US, maintenance requirements and the necessity for backup or spare aircraft are but two reasons why a military aircraft may not be operational. Funds to support the cost of aircraft flight hours are based on a unit's Primary Aircraft Authorization (PAA). PAA is the number of aircraft "...authorized to a unit for the performance of its operation mission." (USAF, 1989b, Ref. 17). PAA is generally some fraction of the total aircraft possessed by a unit. The remaining aircraft allow for "... scheduled and unscheduled maintenance, modifications, and inspections and repair without reduction of aircraft available for the operational mission." (USAF, 1989b, Ref. 17). For example, the ratio of operational aircraft to total possessed aircraft for US Air Force F-15 and F-16 fighter units is approximately 75%. Higher cost aircraft such as bombers, large transports, and electronic surveillance and/or reconnaissance platforms tend to have a higher ratio of operational aircraft to total possessed aircraft. US utilization rates per PAA, based on a sample of representative aircraft programmed flying hours for 1989, and the assumed PAA to total aircraft possessed ratio are tabulated by mission category in Table 5.

Table 4. Representative US Utilization Rates per Primary Aircraft Authorized (PAA)

Mission	PAA to Total Possessed Aircraft Ratio	Utilization (Flying Hours/Year/PAA)
Fighter/ Attack	75%	332
Transport	90%	676
Bomber	90%	374
Trainer	90%	546
Other	75%	335

Other countries do not necessarily use their military aircraft at the same rate as the US, and little unclassified data exists to substantiate non-US military aircraft utilization. Therefore, gross level approximations were assumed that express non-US utilization rates as a percentage of US utilization rates. These approximations result in non-US annual flying hour estimates that do not appear unreasonable for the 1991-1992 time frame.

The product of the inventory count, PAA to total possessed aircraft ratio, US utilization rate, and relative utilization rate yields an estimate of flying hours per year for each region/alliance/country group and mission category. Then, dividing the flying hours per year by the appropriate generic aircraft mission time yields the annual frequency (missions/year) for the generic aircraft type. As an example of this process, consider the CIS Air Force generic transport aircraft T3AFA.

Inventory count:	1111[*]	inventory aircraft
× PAA/inventory count ratio:	0.90	PAA/inventory aircraft
= PAA aircraft:	999	PAA
× Annual US utilization:	676	flying hours/year/PAA
× Relative utilization:	0.75	
= Flying hours:	506,493	flying hour/year
÷ Mission length:	7.63[#]	flying hours/mission
= Annual mission frequency:	66,382	missions/year

Table 5 summarizes the utilization rates, by region and mission, used for the military aircraft operations emissions database.

[*] This inventory count reflects a 60%/40% split of the 1707 total CIS Air Force transport aircraft between generic aircraft types T3AFA and T3AFB.

[#] Generic aircraft mission lengths are included in Appendix A.

Table 5. Utilization Rates and Annual Flying Hours[a] per Inventory Aircraft by Mission and Region

	US/NATO	CIS/Warsaw Pact	China/ Other
Relative Utilization[b]	100%	75%	50%
Fighter/Attack	250 hours	175 hours	125 hours
Transport	600	450	300
Bomber	325	250	175
Trainer	400	300	200
Other	300	225	150

[a] Flying hours rounded to nearest 25 hours.

[b] Relative utilization is percent of US utilization.

Fuel Burn and Engine Exhaust Emissions Estimates

Given the aircraft count; location; mission frequency, profile, and heading; generic aircraft performance in terms of cumulative fuel burn, cumulative distance, and altitude; and engine exhaust emission indices; estimates of fuel burn and engine exhaust emission levels for each generic aircraft type were resolved into a global, three-dimensional database grid. This process was repeated for all military component generic aircraft types, and the resultant grids were summed by cell. The aggregate grid can then be integrated by latitude, longitude, or altitude as necessary. Table 6 summarizes the military component fuel burn and engine exhaust emissions estimates by altitude band for the 1992 scenario. For comparison purposes the 1990 scenario data is presented in Table 7.

Peak fuel burn for the 1992 scenario occurs in the 10-11 km altitude band. NO_x emissions peak in the 0-1 km altitude band for both scenarios although secondary peaks, averaging approximately 65% of the peak values, occur in the 10-11 km altitude band. CO and HC emissions are at their maximum levels in the 11-12 km altitude band for both scenarios.

The electronic file containing these aggregated global estimates was transmitted to NASA Langley Research Center (LRC). This data is available from NASA for investigators via electronic transmission.

Table 6. 1992 Scenario Military Aircraft Operations Component Fuel Burn and Engine Exhaust Emission Estimates

Altitude Band (km)	Fuel (kg × 10^9)	Cumulative Fuel	NO_x (g × 10^9)	Cumulative NO_x	CO (g × 10^9)	Cumulative CO	HC (g × 10^9)	Cumulative HC	Effective EI(NO_x)	Effective EI(CO)	Effective EI(HC)
0-1	3.30	12.9%	46.75	25.9%	26.02	3.2%	5.12	1.3%	14.17	7.89	1.55
1-2	1.56	19.1%	10.69	31.9%	20.82	5.7%	1.69	1.7%	6.84	13.32	1.08
2-3	0.81	22.3%	6.36	35.4%	9.28	6.9%	1.80	2.2%	7.81	11.38	2.20
3-4	0.66	24.9%	4.79	38.1%	8.69	8.0%	1.49	2.6%	7.23	13.11	2.25
4-5	0.45	26.7%	3.37	39.9%	8.06	9.0%	1.24	2.9%	7.51	17.97	2.75
5-6	0.45	28.4%	3.29	41.8%	8.47	10.0%	1.30	3.2%	7.35	18.91	2.90
6-7	1.48	34.2%	7.02	45.7%	33.75	14.2%	1.83	3.7%	4.72	22.73	1.23
7-8	1.85	41.5%	10.29	51.4%	43.16	19.5%	5.09	5.0%	5.57	23.38	2.76
8-9	0.99	45.4%	6.38	54.9%	32.54	23.6%	9.84	7.5%	6.45	32.90	9.94
9-10	2.76	56.2%	18.75	65.3%	91.42	34.9%	18.78	12.4%	6.78	33.07	6.79
10-11	3.84	71.3%	22.73	78.0%	150.95	53.5%	71.15	30.7%	5.93	39.34	18.55
11-12	3.47	84.9%	16.94	87.4%	169.02	74.4%	117.70	61.0%	4.88	48.67	33.89
12-13	2.41	94.4%	14.16	95.2%	112.58	88.3%	66.00	78.0%	5.87	46.66	27.36
13-14	0.86	97.8%	5.42	98.2%	46.82	94.1%	41.14	88.6%	6.34	54.75	48.11
14-15	0.33	99.0%	1.42	99.0%	35.41	98.5%	34.74	97.6%	4.34	108.1	106.2
15-16	0.24	100.0%	1.65	100.0%	11.64	100.0%	9.27	100.0%	6.79	18.17	38.05
Global Total	25.47		180.03		808.65		388.20		7.07	31.73	15.24

Table 7. 1990 Scenario Military Aircraft Operations Component Fuel Burn and Engine Exhaust Emission Estimates

Altitude Band (km)	Fuel (kg × 10^9)	Cumulative Fuel	NO_x (g × 10^9)	Cumulative NO_x	CO (g × 10^9)	Cumulative CO	HC (g × 10^9)	Cumulative HC	Effective EI(NO_x)	Effective EI(CO)	Effective EI(HC)
0-1	3.35	12.9%	44.91	23.1%	27.22	5.6%	5.72	3.0%	13.41	8.13	1.71
1-2	1.66	19.2%	10.96	28.7%	21.22	10.0%	1.75	4.0%	6.60	12.79	1.05
2-3	0.87	22.6%	6.53	32.1%	9.04	11.8%	1.76	4.9%	7.51	10.41	2.03
3-4	0.70	25.3%	4.79	34.6%	8.03	13.5%	1.39	5.6%	6.85	11.47	1.98
4-5	0.47	27.1%	3.33	36.3%	7.05	14.9%	1.08	6.2%	7.12	15.09	2.32
5-6	0.47	28.9%	3.31	38.0%	7.02	16.4%	1.08	6.8%	7.12	15.08	2.32
6-7	1.59	35.0%	7.68	41.9%	26.39	21.8%	1.45	7.5%	4.82	16.55	0.91
7-8	1.99	42.6%	11.56	47.9%	32.16	28.4%	3.76	9.5%	5.82	16.20	1.89
8-9	1.23	47.3%	8.65	52.3%	27.24	34.0%	7.47	13.5%	7.04	22.16	6.08
9-10	2.94	58.6%	22.14	63.7%	62.39	46.8%	12.64	20.2%	7.52	21.20	4.30
10-11	3.90	73.6%	26.62	77.4%	86.12	64.5%	36.29	39.4%	6.83	22.10	9.31
11-12	3.48	87.0%	20.00	87.7%	88.93	82.8%	59.23	70.7%	5.74	25.53	17.00
12-13	2.34	96.0%	16.22	96.0%	55.53	94.2%	30.54	86.9%	6.93	23.71	13.04
13-14	0.63	98.4%	4.94	98.6%	14.31	97.2%	12.04	93.3%	7.87	22.77	19.16
14-15	0.22	99.3%	1.21	99.2%	10.40	99.3%	10.12	98.6%	5.41	46.29	45.06
15-16	0.19	100.0%	1.54	100.0%	3.39	100.0%	2.57	100.0%	8.24	18.17	13.76
Global Total	26.02		194.39		486.44		188.90		7.47	18.69	7.26

CHARTER AND UNREPORTED DOMESTIC TRAFFIC COMPONENTS EMISSIONS

This section describes the syntheses of representative air traffic network models, the generic aircraft used to simulate operations, and the development of fuel burn and engine exhaust emissions estimates for the charter and unreported domestic traffic components. The unreported domestic traffic refers to the scheduled domestic traffic in the CIS, China, and Eastern Europe that is not reported in the Official Airline Guide (OAG, 1992); the bulk of this traffic is carried by Aeroflot.

Air Traffic Network Models

The air traffic network models are supporting databases consisting of routes and associated air traffic levels. Each route is defined by an origin-destination city (or airport) pair, and air traffic is expressed in terms of revenue passenger kilometers (RPK) or available seat kilometers (ASK). Although an origin and destination are specified as a matter of convenience, traffic on the route is nondirectional. For both the charter and unreported domestic traffic components, the most frequently travelled city pairs were identified and all component air traffic was allocated to these city pairs.

The detailed air traffic network models for the charter and unreported domestic traffic components are contained in Appendix B.

Charter Air Traffic

Global charter air traffic totalled 189 billion RPK in 1990 and is forecast, using regional growth factors, to increase to approximately 392 billion RPK by the year 2015 as shown in Figure 5 . While commercial scheduled airliner services have evolved over time into fairly stable global distribution patterns, the charter services do not show such stability. More than 90% of charter air traffic originates in Europe and North America with significantly smaller contributions from Latin America, Middle East and Africa, and the Far East.

The 1992 global charter air traffic network model was constructed by merging European and North American regional traffic network models. Each regional traffic network model accounts for all charter air traffic between the specific region and all global destinations (Statistics Canada, 1988, Ref. 18; ICAO, 1991, Ref.19; Belet and Colomb de Daunant, 1991, Ref. 20; CTI, 1991, Ref. 21). Only 298 origin-destination city pair combinations in the merged traffic network model are active; i.e. air traffic flows between the cities; out of 652 possible origin-destination city pair combinations. Figure 6 indicates that the range distribution of the top 100 origin-destination city pairs (in terms of RPK) is sufficiently similar to the range distribution of all 298 active city pairs. Therefore, these top 100 city pairs formed the basis for the 1992 charter air traffic network model. The 1992 charter air traffic, as a result of world economic conditions, was slightly less than the forecast 194.6 billion RPK forecast shown in Figure 5, and was reported at 186 billion RPK. For the 1992, this charter traffic was apportioned among these top 100 origin-destination city pairs.

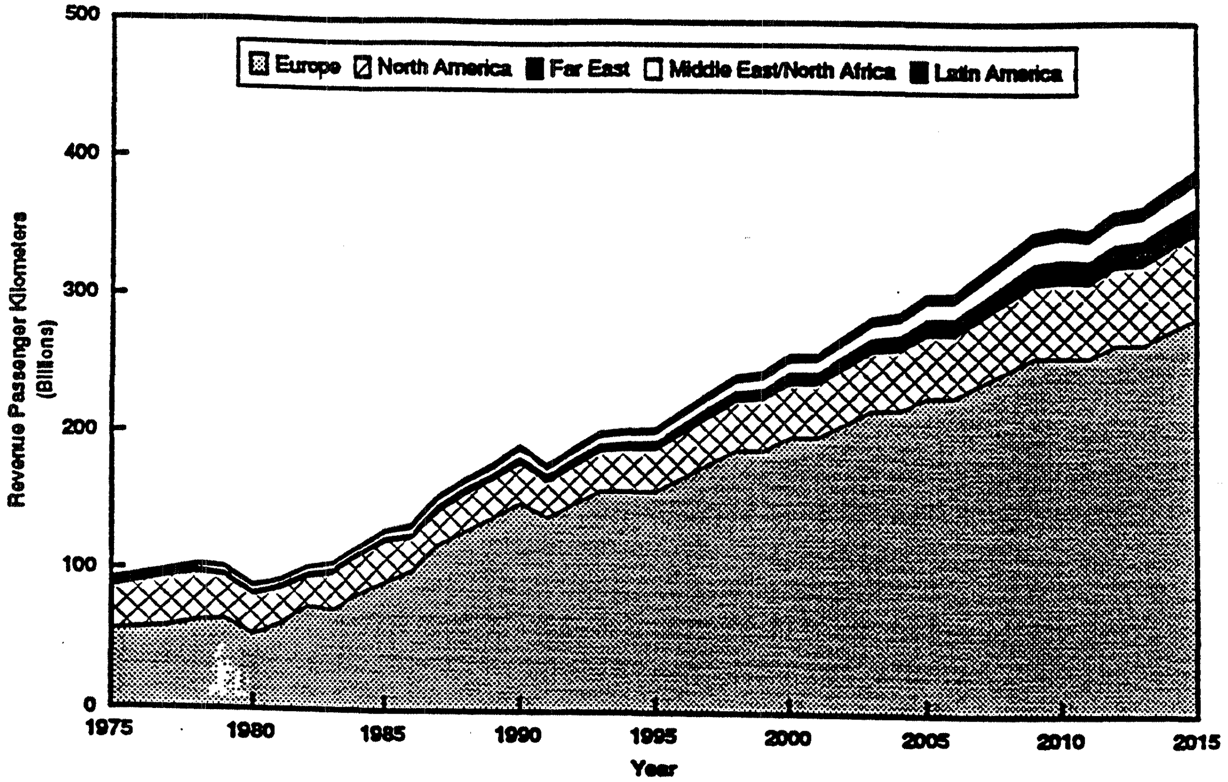


Figure 5. History and forecast of charter traffic growth. Europe and North America account for well over 90% of the traffic. Regions are from where traffic originates.

Unreported Domestic Air Traffic

The Russian carrier Aeroflot is the dominant carrier in the region which this component represents. Therefore, its domestic network structure formed the kernel of the unreported domestic air traffic network model. An MDC simulation of Aeroflot's July 1992 domestic passenger flight schedule contains 264 routes with a wide range of service frequencies. The top 86 of these routes, by service frequency, yields a network model which adequately represents the geographical distribution of Aeroflot's domestic network. The final unreported domestic traffic network model includes five additional routes to account for the remaining unreported Eastern European and Chinese domestic traffic. A total of 248 billion ASK, consisting of 219 billion ASK from the CIS, 21 billion ASK from China, and 9 billion ASK from Eastern Europe, was apportioned among the 91 routes to create the air traffic network model for the 1992 scenario.

Charter and Unreported Domestic Traffic Components Generic Aircraft and Emission Indices

The 1992 global charter fleet included aircraft with many capacities, ranges, and vintages. The distribution of aircraft in the European charter fleet (Belet and Colomb de Daunant, 1991, Ref. 20), shown in Figure 7, provides a representative sample of this aircraft mix. Similarly,

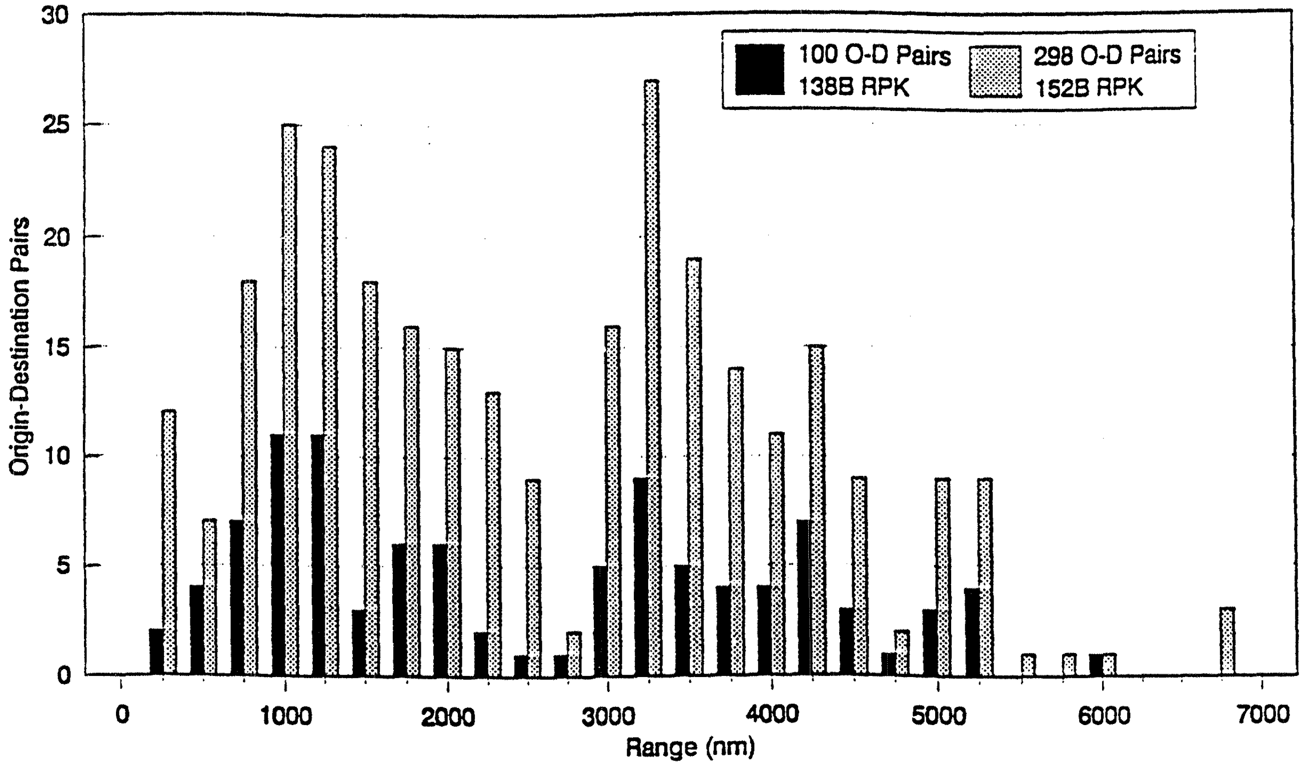


Figure 6. Cumulative distribution of ranges between selected origin-destination city pairs that have a positive 1990 charter air traffic level. Top 100 city pairs formed the basis for the charter network.

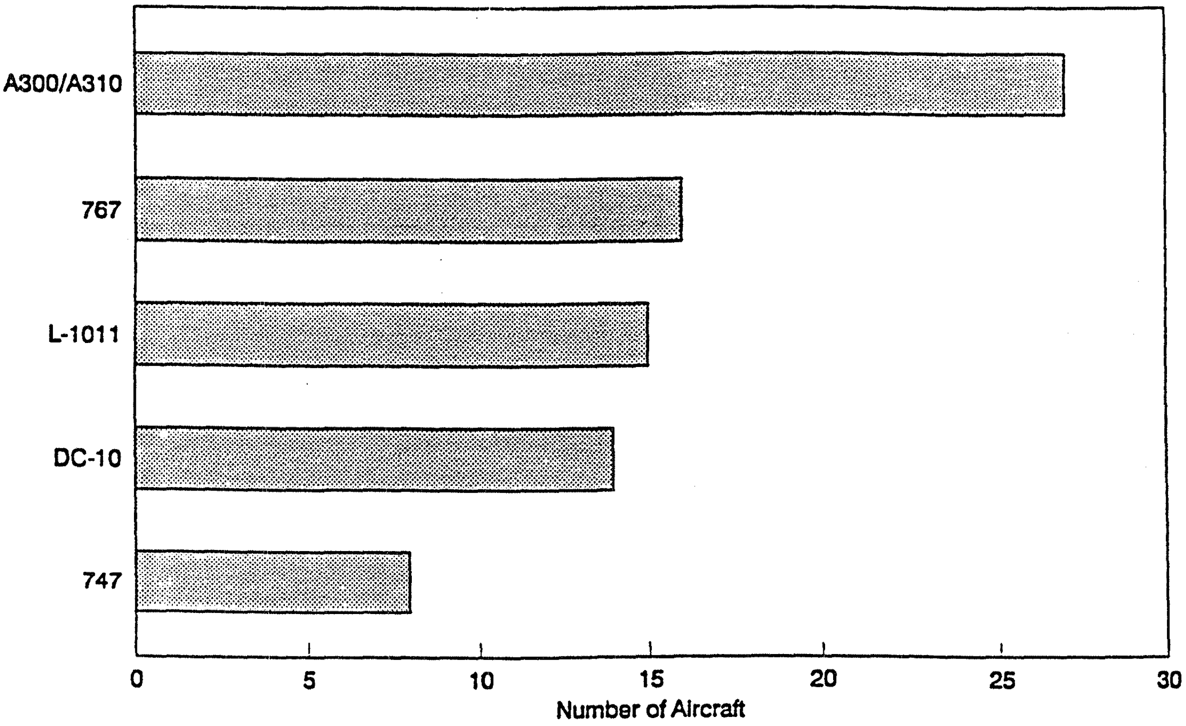


Figure 7. Distribution of aircraft types in the 1992 European charter traffic fleet. The generic aircraft used to model charter traffic fuel burn and emission reflect charactersitics of these aircraft.

Figure 8 indicates the relative distribution of aircraft types in the 1992 Aeroflot fleet that served domestic traffic needs.

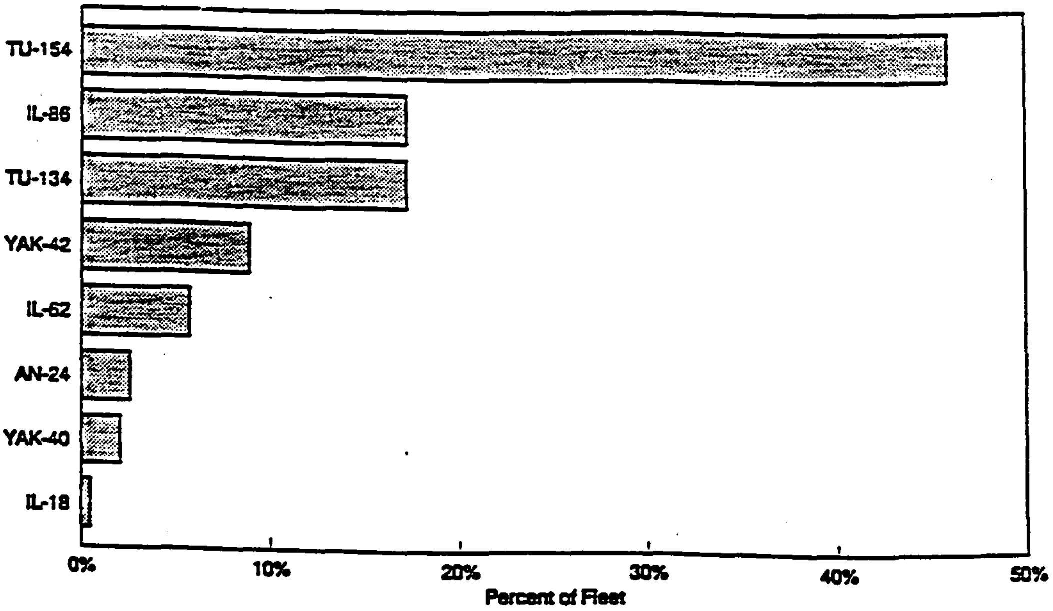


Figure 8. Relative distribution of aircraft in Aeroflot's 1992 domestic fleet. Genric aircraft with similar characteristics were used to develop fuel burn and emission estimates.

Six generic aircraft were used for the charter component to model fuel burn and engine exhaust emissions for both the 1990 and 1992 scenarios; the unreported domestic traffic component employed three generic aircraft. The use of generic aircraft parallels that employed in the military emissions estimates. Assignment of a generic aircraft to a route was defined by the charter route's range and capacity requirements. Specifically, generic aircraft C1 was assigned to routes less than 2800 km and requiring less than 136 passenger capacity; C2, 2800 km to 4650 km and less than 136 passengers; C3, greater than 4650 km and less than 136 passengers; C4, all ranges and 137 to 172 passengers; C5, less than 4650 km and greater than 172 passenger; and C6, greater than 4650 km and greater than 172 passengers.

The unreported domestic traffic component used no explicit range and/or capacity generic aircraft assignment logic although, in most cases, the generic aircraft assigned to a specific route had characteristics similar to the aircraft actually employed on the route. Generic aircraft S1 has a nominal capacity of 316 passengers and a nominal range of 6150 km; S2, 73 passengers and 1750 km; and S3, 132 passengers and 4750 km. The same generic aircraft (and therefore fuel consumption rates) and emission indices were used for the year 1992 scenario estimates.

Appendix B includes additional details on the charter and unreported domestic traffic components' generic aircraft and associated engine exhaust emission indices.

Flight Profiles

For each of the top 100 charter and 91 unreported domestic city pairs, a single generic aircraft type, assigned by range and capacity, was assumed to carry all annual traffic on a great circle route between the pairings. The generic aircraft capacity dictates the number of flights that must be completed annually to carry all apportioned traffic. Block fuel and block time equations, both functions of great circle distance, are available for each generic aircraft. Block fuel is the sum of ground maneuver fuel, climb fuel, cruise fuel, descent fuel, and approach fuel. Block time is defined in a similar manner. These performance equations, together with the required number of flights, yielded annual estimates of fuel burn and aircraft hours for each route in the air traffic network models.

An aircraft's fuel burn on a route is not linear with distance. For the ground distance covered, an aircraft uses a relatively large amount of fuel in the initial climb. Similarly, an aircraft burns a relatively small amount of fuel while flying typical descent schedules. Taxi-out and takeoff operations concentrate fuel burn at the origin while approach, landing, and taxi-in operations concentrate fuel burn at the destination. Although fuel consumed during the initial climb and descent phases of flight depends on factors such as initial cruise altitude, final cruise altitude, takeoff gross weight and landing gross weight, constant amounts typical of each generic aircraft's class were assumed for both the climb and descent phases of flight. Therefore, these representative values for engine start, taxi-out, takeoff, climb, descent, approach, land, and taxi-in fuel burns were subtracted from block fuel. Similarly, representative climb and descent distances were subtracted from the great circle distance. The remaining block (or cruise) fuel was then linearly allocated over the remaining great circle distance. Next, the fuel burn was allocated to the appropriate altitude.

Several considerations influence an aircraft's cruise altitude including segment range, aircraft operating characteristics, type of cruise (step-climb, cruise-climb, constant altitude cruise, etc.), traffic, weather, and direction of flight. This analysis assumed aircraft operate using either constant altitude cruise or cruise-climb profiles at altitudes representative of typical operations. These altitudes range from 15,000 feet for short range, twin-jet operation to 37,000 feet for long range, wide-body operation. All fuel was linearly allocated between the initial and final altitudes.

Fuel Burn and Exhaust Emissions Estimates

Table 8 and Table 9 contain the 1992 scenario and 1990 scenario fuel burn and engine exhaust emission estimates, respectively, for the total charter and unreported domestic traffic components, arranged by altitude band. Unlike the military emissions, which has no discernable seasonality trends, the charter and unreported domestic emissions have distinctive traffic patterns. Table 10 contains the aggregated 1992 total charter and unreported domestic traffic components reflecting individual estimated monthly seasonality effects.

Peak fuel burn and exhaust emissions levels for both the 1992 and 1990 scenarios occur in the 10-11 km altitude band. Both CO and HC emissions have small secondary peaks (5% and

9% of peak values) in the 0-1 km altitude band. Peak monthly emissions occur during the highly travelled Northern Hemisphere summer season, a comparable trough occurs during the late winter months.

Electronic files containing these estimates for each traffic sector, were transmitted to NASA LRC. These files consisted of individual files for both annualized charter and unreported domestic traffic, and individual monthly files for both sectors reflective of seasonality effects. These data sets are available from NASA for use by investigators via electronic transmission.

Table 8. 1992 Scenario Charter and Unreported Domestic Traffic Components Fuel Burn and Engine Exhaust Emission Estimates

Altitude Band (km)	Fuel (kg × 10^9)	Cumulative Fuel	NO_x (g × 10^9)	Cumulative NO_x	CO (g × 10^9)	Cumulative CO	HC (g × 10^9)	Cumulative HC		Effective	
									EI(NO_x)	EI(CO)	EI(HC)
0-1	0.38	2.5%	2.31	2.8%	6.38	7.5%	1.07	4.8%	6.12	16.93	2.85
1-2	0.38	4.9%	3.74	7.6%	1.23	8.1%	0.16	4.7%	9.93	3.27	0.43
2-3	0.38	7.4%	3.72	12.3%	1.29	9.4%	0.17	5.4%	9.90	3.44	0.46
3-4	0.40	9.9%	3.75	17.1%	1.36	10.7%	0.18	6.0%	9.97	3.61	0.48
4-5	0.36	12.5%	3.96	22.4%	1.55	12.7%	0.19	6.8%	9.79	3.84	0.48
5-6	0.37	14.9%	3.50	26.5%	1.44	13.5%	0.20	7.4%	9.70	4.00	0.55
6-7	0.35	17.3%	3.47	30.4%	1.56	14.7%	0.22	7.8%	9.44	4.25	0.59
7-8	0.35	19.5%	3.24	35.4%	1.55	17.0%	0.21	9.1%	9.27	4.42	0.60
8-9	0.35	21.8%	3.14	39.5%	1.63	18.6%	0.22	10.0%	9.03	4.67	0.63
9-10	2.61	38.9%	19.50	62.8%	26.62	58.1%	3.62	33.4%	7.46	10.18	1.39
10-11	7.68	89.1%	36.70	82.2%	129.21	87.1%	35.93	94.7%	4.78	16.82	4.68
11-12	1.27	97.4%	10.45	95.0%	16.92	96.5%	1.96	99.0%	8.24	13.33	1.54
12-13	0.39	100.0%	3.35	100.0%	6.54	100.0%	0.61	100.0%	8.56	16.68	1.55
Global Total	15.29		100.83		197.28		44.74		6.59	12.90	2.93

Table 9. 1990 Scenario Charter and Unreported Domestic Traffic Components Fuel Burn and Engine Exhaust Emission Estimates

Altitude Band (km)	Fuel (kg × 10^9)	Cumulative Fuel	NO_x (g × 10^9)	Cumulative NO_x	CO (g × 10^9)	Cumulative CO	HC (g × 10^9)	Cumulative HC	Effective EI(NO_x)	Effective EI(CO)	Effective EI(HC)
0-1	0.38	2.5%	2.27	2.1%	6.38	5.5%	1.05	4.1%	6.02	16.89	2.78
1-2	0.38	5.1%	3.67	5.4%	1.17	6.5%	0.15	4.7%	9.72	3.10	0.40
2-3	0.38	7.6%	3.66	8.8%	1.17	7.5%	0.15	5.3%	9.72	3.10	0.40
3-4	0.38	10.1%	3.66	12.2%	1.17	8.5%	0.15	5.8%	9.72	3.10	0.40
4-5	0.41	12.8%	3.90	15.7%	1.26	9.6%	0.15	6.4%	9.64	3.12	0.38
5-6	0.37	15.3%	3.61	19.0%	1.15	10.6%	0.16	7.0%	9.76	3.11	0.42
6-7	0.37	17.8%	3.58	22.3%	1.15	11.6%	0.16	7.7%	9.74	3.11	0.43
7-8	0.35	20.1%	3.43	25.5%	1.07	12.5%	0.14	8.2%	9.80	3.06	0.40
8-9	0.35	22.4%	3.41	28.6%	1.07	13.4%	0.14	8.7%	9.80	3.06	0.40
9-10	2.61	39.9%	21.72	48.5%	16.50	27.6%	2.20	17.3%	8.31	6.31	0.84
10-11	7.37	89.3%	40.58	85.7%	72.05	89.6%	20.00	94.8%	5.51	9.78	2.71
11-12	1.23	97.5%	11.90	96.6%	8.91	97.2%	1.03	98.8%	9.71	7.27	0.84
12-13	0.37	100.0%	3.76	100.0%	3.20	100.0%	0.30	100.0%	10.10	8.60	0.80
Global Total	14.93		109.16		116.24		25.78		7.31	7.79	1.73

Table 10. 1992 Scenario Charter and Unreported Domestic Traffic Components Fuel Burn and Engine Exhaust Emission Monthly Estimates

Month	Fuel ($kg \times 10^7$)	NO_x ($g \times 10^9$)	CO ($g \times 10^9$)	HC ($g \times 10^9$)
January	121.5	7.97	15.78	3.60
February	119.0	7.81	15.44	3.52
March	115.8	7.60	15.04	3.43
April	122.9	8.06	15.96	3.63
May	129.8	8.56	16.76	3.80
June	136.8	9.18	17.51	3.94
July	140.9	9.37	17.96	4.04
August	140.0	9.31	17.85	4.02
September	133.3	8.77	17.10	3.86
October	124.5	8.21	16.08	3.65
November	123.0	8.08	15.97	3.64
December	122.0	8.01	15.83	3.61
Ave. Month	127.4	8.22	16.44	3.73

VALIDATION

The procedures and software tools used for developing the 1992 database were similar to those employed developing the 1990 military database. MDC personnel continued to monitor the performance of the specialized software packages utilized in creating the emission grid. One improvement added to the procedure was the addition of a methodology to model atmospheric effects on emission indices (Martin, 1993, Ref. 8). To ensure each software unit was functionally correct, each was tested in a stand alone environment. Direct comparisons of results from each unit to manual results were made. Comparisons to manual results continued at each stage of incorporation of new software into the pre-existing database development tools. Overall results were compared to the 1990 database for reasonableness. In addition these estimates were also compared to other independent results. The accuracy of such estimates, while difficult to validate in either the aggregate or on a geographic basis have been cross correlated with varying sources (Balashov, 1992, Ref.22; EIA, 1993, Ref. 23; Forecast International, 1992, Ref. 24; Reed, 1992, Ref. 25) and with experts in the field.

SUMMARY

MDC modeled global 1992 aircraft operations to estimate fuel burn and engine exhaust emission levels for the military, charter, and unreported domestic traffic components for a 1992 scenario. In support of AESA, the Boeing Commercial Airplane Group (BCAG) has been developing databases defining scheduled commercial traffic emissions. The MDC databases, together with the BCAG developed databases, will provide the SASS a cornerstone for assessing the environmental impact of subsonic aviation.

Although specific comments regarding the impact of these estimates remain to be made by SASS investigators, two overall comparisons can be drawn the previously developed 1990 databases. One effect of the gradual worldwide drawdown of military forces is observed in the 1992 total military fuel usage. The 1992 military database represents 25.5 x 10^9 kilograms of worldwide fuel, a 2.1 percent reduction from 1990 (26.0 x 10^9 kilograms). Conversely, the Charter/Unreported Traffic component worldwide fuel usage grew by 2.4 percent, increasing from 14.9 x 10^9 kilograms in 1990 to 15.3 x 10^9 kilograms in 1992.

REFERENCES

1. Bahr, D. W., Turbine engine developers explore ways to lower NO_X emission levels, *ICAO Journal,* p. 14, August, 1992.

2. NASA Contractor Report 4613, *Jet Engine Exhaust Emissions Database Development - Year 1990 and 2015 Scenarios,* Contract NAS1-19345, Langley Research Center, VA, 1994.

3. Barr, P. A., A. K. Grothues, Z. H. Landau, M. Metwally, J. Morgenstern, A. K. Mortlock, R. Van Alstyne, and C. A. Ward, Emissions scenarios development: scenario database development at McDonnell Douglas Corporation, in *The Atmospheric Effects of Stratospheric Aircraft: A Third Program Report,* (R. S. Stolarski and H. L. Wesoky, Eds.), NASA Reference Publication 1313, November 1993.

4. OAG, *Official Airline Guide,* Official Airline Guides, Inc., Oak Brook, IL, July, 1992.

5. Pace, R. G., *Aircraft Emissions Factors,* PB-275 067, Environmental Protection Agency, Ann Arbor, MI, 1977.

6. Sears, D. R., *Air Pollutant Emission Factors for Military and Civil Aircraft,* Lockheed Missiles and Space Co. Contract No. 68-02-2614 for Office of Air Quality Planning and Standards, Environmental Protection Agency, Research Triangle Park, NC, 1978.

7. ICAO, ICAO engine exhaust emissions databank, presented at ICAO Committee on Aviation Environmental Protection Working Group 3 Meeting, Mariehamn, Aland, October 10-13, 1989.

8. Martin, R. L., *Response to Inquiry at AIA EPG Meeting of 12/8-9/92 Regarding Emissions Fuel Flow Correlation Procedure*, Boeing Commercial Airplane Group, May 1993.

9. Munt, R., and E. Danielson, *Aircraft Technology Assessment Status of The Gas Turbine Program,* PB-277 351, Environmental Protection Agency, Ann Arbor, MI, 1976.

10. *Air Force Magazine,* Guide to Air Force installations worldwide, May, 1992.

11. International Institute for Strategic Studies, *The Military Balance 1991-1992,* Brassey's, London, 1991.

12. International Media Corporation, *Defense and Foreign Affairs Handbook,* 1990-1991 Ed., Alexandria, VA, 1990.

13. DMA, Automated airfield information file, Defense Mapping Agency Aerospace Center, St. Louis, MO, 1991.

14. *MILAV News,* p. 429, September, 1991.

15. USAF, Standard aircraft characteristics and performance, piloted aircraft (fixed wing), MIL-C-005011B, US Department of the Air Force, Washington DC, 1977.

16. USAF, USAF standard aircraft/missile characteristics, AFG 2, US Department of the Air Force, Washington, DC, 1989a.

17. USAF, U.S. Air Force cost and planning factors, AFR 173-13, US Department of the Air Force, Washington, DC, 1989b.

18. Statistics Canada, *Air Charter Statistics 1987,* Minister of Supplies and Services, Ottawa, 1988.

19. ICAO, *Traffic - Commercial Air Carriers 1986-1990,* Digest of Statistics No. 379, International Civil Aviation Organization, Montreal, 1991.

20. Belet, D., and L. Colomb de Daunant, *European Charter Airlines Strategies for the 90s,* Institute of Air Transport, Paris, 1991.

21. CTI, *United States International Air Travel Statistics Calendar Year 1990,* Center for Transportation Information, Cambridge, MA, 1991.

22. Balashov, B., and A. Smith, ICAO analyses trends in fuel consumption by world's airlines, *ICAO Journal,* p. 18, August, 1992.

23. EIA, *Petroleum Supply Monthly,* Energy Information Administration, US Department of Energy, Washington, DC, February, 1993.

24. Forecast International/DMS Market Intelligence Report, *Military Aircraft Forecast,* Forecast International, Newton, CT, 1992.

25. Reed, C., N. Cook, J. Boatman, and J. A. C. Lewis, Market survey, *Jane's Defence Weekly, 1992.*

APPENDIX A: Military Aircraft Operations Component

This appendix contains data used to generate the military aircraft operations component exhaust emissions estimates. The table below shows the military aircraft inventory upon which the 1992 scenario military component database was based. The fighter/attack mission category includes fighter, attack, and dual-capable aircraft used in air-to-air combat, ground attack, air defense, and some counter-insurgency and forward air control roles. Transport aircraft, both short and long range, and tanker aircraft are counted in the transport mission category. The other category includes aircraft primarily performing maritime patrol, electronic warfare and intelligence, reconnaissance and surveillance, and special operations missions.

	Mission					
Region/Alliance/Country	Fighter/ Attack	Transport(a)	Bomber	Trainer	Other	Total
CIS						
CIS Air Force	4250	1525	360	1000	585	7720
CIS Navy	315	182	391		61	949
CIS Subtotal	4565	1707	751	1000	646	8669
US						
US Air Force	3544	1805	312	1479	996	8136
US Navy	1456	201		719	770	3146
US Subtotal	5000	2006	312	2198	1766	11,282
Asia/Australasia						
India	555	222	10	283	46	1116
Japan	302	88		237	189	816
Taiwan	424	81		120	43	668
North Korea	582	30	80	60		752
Pakistan	315	21			20	356
South Korea	317	36		99	52	504
Vietnam	60	82			6	148
Afghanistan	210	13		43		266
Thailand	130	62		96	36	324
Australia	89	62		110	50	311
Singapore	147	16		30	8	201
Indonesia	66	65			27	158

	Mission					
Region/Alliance/Country	Fighter/ Attack	Transport[a]	Bomber	Trainer	Other	Total
Malaysia	49	37			7	93
Bangladesh	81	5		36		122
Philippines	9	38		8	11	66
Mongolia	12	23		5		40
Laos	30	9		4		43
New Zealand	21	16		17	9	63
Burma	37	12		9		58
Sri Lanka		13			7	20
Cambodia	20					20
Papua - New Guinea		5			3	8
Nepal		3				3
Asia/Australasia Subtotal	3456	939	90	1157	514	6156
NATO						
France	594	211	18	383	137	1343
UK	540	110		360	133	1143
Germany	325	171		86	111	693
Italy	297	239		151	52	739
Turkey	404	146		102	56	708
Greece	268	96		46	43	453
Spain	249	71		123	54	497
Canada	146	59		211	50	466
Netherlands	144	14		17	22	197
Belgium	126	52		31		209
Portugal	56	20		63	19	158
Denmark	97	6		9		112
Norway	61	12		20	6	99
Luxembourg		20				20
Iceland	18				11	29
NATO Subtotal	3325	1227	18	1602	694	6866

	Mission					
Region/Alliance/Country	Fighter/ Attack	Transport[a]	Bomber	Trainer	Other	Total
China						
China Air FoOrce	4500	158	470		290	5418
China Navy	700	60	160		20	940
China Subtotal[b]	5200	218	630	0	310	6358
Middle East/North Africa						
Iraq	255	10	6	80		351
Israel	524	99		128	45	796
Libya	379	74	5	161	13	632
Syria	484	28		191	6	709
Egypt	411	25		162	33	631
Saudi Arabia	214	116		72	15	417
Algeria	202	42		45	5	294
Iran	110	77		93	8	288
Jordan	94	13		53		160
Morocco	93	29			8	130
South Yemen						0
UAE	74	8		30	15	127
North Yemen	95	24		6		125
Oman	50	23				73
Kuwait	34					34
Somali Republic						0
Sudan	45	20		12	2	79
Tunisia	41	2		8		51
Qatar	18	3				21
Bahrain	24	2				26
Mauritania	5	3			2	10
Lebanon	3	2		3		8
Djibouti		4				4
Middle East/North Africa Subtotal	3155	604	11	1044	152	4966

	Mission					
Region/Alliance/Country	Fighter/ Attack	Transport[a]	Bomber	Trainer	Other	Total
Caribbean/Latin America						
Brazil	144	193		321	63	721
Argentina	136	97	6	109	21	369
Cuba	146	40		64		250
Peru	94	91		43	13	241
Mexico	110	75		51	20	256
Chile	109	30		80	13	232
Venezuela	94	54		45	3	196
Ecuador	56	24			3	83
Bolivia	28	26		38	2	94
Colombia	71	57			3	131
Honduras	33	25		22		80
Uruguay	26	18			13	57
Guatemala	16	18		6		40
Paraguay	6	14		31		51
El Salvador	16	12		10		38
Nicaragua	6	6		17		29
Dominican Republic	8	10				18
Panama		1			3	4
Guyana		8				8
Haiti		2				2
Suriname	5					5
Bahamas		3				3
Jamaica		3				3
Costa Rica					8	8
Belize		2				2
Trinidad		1				1
Caribbean/Latin America Subtotal	1104	810	6	837	165	2922

			Mission			
Region/Alliance/Country	Fighter/ Attack	Transport[a]	Bomber	Trainer	Other	Total
Warsaw Pact						
Poland	294	32			31	357
Czechoslovakia	144	31		92	38	305
Romania	310	27		124	27	488
East Germany						0
Bulgaria	192	15		138	65	410
Hungary	69	14			11	94
Warsaw Pact Subtotal	1891	207	0	328	137	1654
Sub-Sahara Africa						0
South Africa	43	47		127	87	304
Angola	136	47		14	19	216
Ethiopia	68	11		14		93
Nigeria	93	58		2	2	155
Zambia	51	20		32		103
Zimbabwe	65	25				90
Mozambique	43	7		4		54
Zaire	28	20		3		51
Kenya	28	16				44
Mali	16	4		7		27
Congo	32	7		5		44
Tanzania	24	8		2		34
Uganda	13					13
Cameroon	16	11			2	29
Gabon	9	17			1	27
Madagascar	12	13				25
Botswana	13	6				19
Togo	13	4				17
Guinea	12	2		5		19

	Mission					
Region/Alliance/Country	Fighter/ Attack	Transport(a)	Bomber	Trainer	Other	Total
Ghana	6	14				20
Burkina Faso	8	7				15
Senegal	5	7			1	13
Côte d'Ivoire	6	6				12
Chad	2	10				12
Niger		11				11
Malawi		11				11
Benin		7				7
Rwanda		7				7
Equatorial Guinea		1				1
Central African Republic		3				3
Guinea-Bissau	3					3
Cape Verde						0
Seychelles		1			1	2
Burundi						0
Sub-Sahara Africa Subtotal	745	408	0	215	113	1481
Non-Aligned Europe						
Sweden	317	10		127	66	520
Yugoslavia	285	37			65	387
Switzerland	271	2		44	18	335
Finland	90	3			3	96
Albania	95	9		10		114
Austria	54	2		24		80
Ireland	6	3			2	11
Cyprus		3				3
Non-Aligned Europe Subtotal	1118	69	0	205	154	1546
Global Total	28,677	8107	1818	8612	4686	51,900

(a) Aerial refueling (tanker) aircraft included in this category: France, 11; UK, 29; Spain, 7; Canada, 2; Luxembourg, 20; US Air Force, 651; US Navy, 93; and CIS Air Force, 81.

(b) China's trainer aircraft quantity is unknown and may be included in the reported fighter/attack aircraft numbers.

The table below specifies the generic aircraft nomenclature by region/alliance/country group and mission.

	Generic Aircraft Designator(a)					
Region/Alliance/Country	**Fighter/Attack**	**Transport**	**Bomber**	**Tanker**	**Trainer**	**Other**
CIS	F3AF	T3AFA	B3AF	TK3AF	TR3AF	R3AF
	F3N	T3AFB	B3N			R3AN
		T3AN				R3BN
		T3BN				
US	F1AA	T1AA	B1	TK1A	TR1A	R1AA
	F1AB	T1AB		TK1BA	TR1BA	R1AB
	F1AC	T1BA		TK1BB	TR1BB	R1BA
	F1AD	T1BB				R1BB
	F1B					
Asia/Australasia	F8	T8A	B8		TR8	R8A
		T8B				R8B
NATO	F2	T2A	B2		TR2	R2A
		T2B				R2B
China	F5	T5A	B5			R5
		T5B				
Middle East/North Africa	F9	T9A	B9		TR9A	R9
		T9B			TR9B	
Caribbean/Latin America	F7A	T7	B7		TR7A	R7A
	F7B				TR7B	R7B
Warsaw Pact	F4	T4			TR4	R4
Sub-Sahara Africa	F10	T10A			TR10	R10
		T10B				
Non-Aligned Europe	F6	T6			TR6	R6

(a) Any similarity between generic aircraft designators and actual military aircraft identifiers is coincidental.

The next table indicates the mission distance, mission fuel consumption, maximum altitude achieved, and engine type for each generic aircraft. All missions were radial missions; therefore, the mission distance is a round-trip distance.

Generic Aircraft	Mission Distance (km)	Mission Time (hr)	Mission Fuel (kg)	Maximum Altitude (km)	Engine Type
B1	15,467	18.10	116,587	15.2	E11
B2	2224	2.66	7045	10.4	E4B
B3AF	15,467	18.10	64,770	15.2	E11
B3N	3669	4.47	21,612	11.2	E4A
B5	3669	4.47	6754	11.2	E4A
B7	2224	2.66	10,064	10.4	E4B
B8	2224	2.66	3019	10.4	E4B
B9	2224	2.66	12,077	10.4	E4B
F1AA	2548	3.20	4891	13.7	E3
F1AB	1262	1.53	4371	15.2	E2
F1AC	555	2.18	3517	7.6	E1
F1AD	1854	2.33	9420	12.5	E10
F1B	262	1.53	2623	15.2	E2
F2	1854	2.33	8478	12.5	E10
F3AF	1854	2.33	7536	12.5	E10
F3N	1297	2.31	3334	12.2	E9
F4	1110	2.68	5089	11.7	E8
F5	1110	2.68	3957	11.7	E8
F6	1297	2.31	3704	12.2	E9
F7A	1110	2.68	3957	11.7	E8
F7B	1110	3.57	774	2.4	E15
F8	1110	2.68	3732	11.7	E8
F9	1297	2.31	4816	12.2	E9
F10	1297	2.31	3588	12.2	E9
R1AA	2222	5.27	4057	6.1	E14
R1AB	1854	2.33	9420	12.5	E10
R1BA	555	2.18	5275	7.6	E1
R1BB	4321	8.67	16,057	7.6	E13
R2A	1854	2.33	9420	12.5	E10
R2B	2222	5.27	5164	6.1	E14

Generic Aircraft	Mission Distance (km)	Mission Time (hr)	Mission Fuel (kg)	Maximum Altitude (km)	Engine Type
R3AF	1854	2.33	11,304	12.5	E10
R3AN	3669	4.47	13,507	11.2	E4A
R3BN	3674	7.63	21,002	11.4	E12A
R4	1110	2.68	3393	11.7	E8
R5	1297	2.31	1852	12.2	E9
R6	1110	2.68	2375	11.7	E8
R7A	1110	2.68	2036	11.7	E8
R7B	1110	3.57	1549	2.4	E15
R8A	1110	3.57	1549	2.4	E15
R8B	4321	8.67	14,273	7.6	E13
R9	1854	2.33	8478	12.5	E10
R10	1110	2.68	1696	11.7	E8
T1AA	3835	7.63	14,001	11.4	E12A
T1AB	14,815	19.44	107,410	12.5	E6A
T1BA	2222	5.27	4426	6.1	E14
T1BB	3706	5.63	13,644	9.1	E7
T2A	1864	3.80	4743	10.7	E12B
T2B	1110	3.57	1239	2.4	E15
T3AFA	3835	7.63	15,401	11.4	E12A
T3AFB	14,815	19.44	96,669	12.5	E6A
T3AN	3835	7.63	15,401	11.4	E12A
T3BN	3669	4.47	13,507	11.2	E4A
T4	2222	5.27	5902	6.1	E14
T5A	2222	5.27	3320	6.1	E14
T5B	3835	7.63	15,401	11.4	E12A
T6	1864	3.80	5420	10.7	E12B
T7	2222	5.27	3689	6.1	E14
T8A	1110	3.57	4646	2.4	E15
T8B	1864	3.80	6776	10.7	E12B
T9A	2222	5.27	6640	6.1	E14

Generic Aircraft	Mission Distance (km)	Mission Time (hr)	Mission Fuel (kg)	Maximum Altitude (km)	Engine Type
T9B	3705	4.81	45,279	12.5	E6B
T10A	2222	5.27	8853	6.1	E14
T10B	1110	3.57	1549	2.4	E15
TK1A	7268	9.75	39,217	11.9	E5
TK1BA	555	2.18	8440	7.6	E1
TK1BB	3835	7.63	14,001	11.4	E12A
TK3AF	7268	9.75	31,374	11.9	E5
TR1A	1110	2.68	1018	11.7	E8
TR1BA	1110	2.68	3054	11.7	E8
TR1BB	1110	3.57	464	2.4	E15
TR2	1110	2.68	1018	11.7	E8
TR3AF	1110	2.68	1357	11.7	E8
TR4	1297	2.31	3704	12.2	E9
TR6	1110	2.68	1018	11.7	E8
TR7A	1110	2.68	1018	11.7	E8
TR7B	1110	3.57	774	2.4	E15
TR8	1110	2.68	1357	11.7	E8
TR9A	1110	2.68	1018	11.7	E8
TR9B	1110	3.57	464	2.4	E15
TR10	1110	2.68	1018	11.7	E8

The exhaust emission indices in the table below correspond to the generic aircraft engine type specified above. The nitrogen oxides (NO_X), carbon monoxide (CO), and unburned hydrocarbons (HC) exhaust emission indices are indexed by altitude band and were derived by weight averaging calculated generic aircraft fuel flows in the appropriate altitude band and then, using the resultant weighted average fuel flow, linearly interpolating the raw engine emission indices.

	Altitude Band Upper Limit	Emission Indices (g/kg)		
Engine	(km)	NO_X(a)	CO	HC
E1	1	7.0	11.1	0.6
	6	6.8	9.7	0.5
	30	7.5	15.4	0.7
E2	1	40.8	8.0	0.1
	12	25.3	2.5	0.4
	30	9.4	6.7	1.0
E3	1	19.4	2.7	0.5
	10	12.8	2.9	0.6
	30	10.3	4.6	0.8
E4A	1	25.8	2.9	0.3
	8	15.4	13.3	5.2
	30	6.1	38.7	15.3
E4B	1	25.6	3.2	25.6
	8	15.4	13.4	15.4
	30	6.6	37.5	6.6
E5	1	16.8	0.9	0.1
	8	13.2	2.0	0.1
	10	8.6	3.5	0.1
	30	6.8	11.5	0.6
E6A	1	7.5	8.0	3.3
	10	8.1	5.5	2.1
	30	5.6	33.7	31.2
E6B	1	7.5	7.9	3.3
	10	8.5	3.8	1.3
E8	1	5.0	21.5	1.4
	2	6.2	12.4	0.3
	7	5.0	20.9	1.3
	30	4.5	26.2	2.2
E9	1	6.9	7.2	2.2
	10	4.1	18.8	9.5
	30	5.4	13.5	6.1
E10	1	14.4	5.7	1.4
	10	7.6	23.3	4.3
	30	7.7	22.9	4.2
E11	1	9.2	1.8	0.4
	10	8.5	4.1	1.5
	13	4.6	48.5	47.6
	30	3.1	69.0	70.3
E12A	1	8.1	2.4	0.2
	7	6.4	3.0	0.3
	11	6.4	3.0	0.3
	30	3.7	10.9	9.0
E12B	1	8.6	2.2	0.2
	7	6.8	2.9	0.3
	30	4.6	8.2	6.0
E13	1	7.9	2.5	0.2
	4	6.0	3.9	1.2
	30	6.4	3.0	0.3

Engine	Altitude Band Upper Limit (km)	Emission Indices (g/kg) NO_X[a]	CO	HC	Engine	Altitude Band Upper Limit (km)	Emission Indices (g/kg) NO_X[a]	CO	HC
	30	5.7	32.0	29.3	E14	1	2.9	16.7	1.0
E7	1	7.6	1.9	0.5		6	1.5	28.3	0.3
	9	6.8	2.0	0.6		30	1.5	27.9	0.3
	30	6.3	2.1	0.6	E15	1	5.8	23.9	14.7
						2	6.9	13.1	6.9
						30	8.1	4.8	1.7

[a] NO_X emission index in g of NO_X as NO_2 emitted per kg of fuel.

The locations at which each country's generic aircraft were based are indicated in the table below.

Region/Alliance/ Country-Deployment	Latitude	Longitude	Region/Alliance/ Country-Deployment	Latitude	Longitude
CIS[a]			Middle East/North Africa		
Northern Front	62°30′N	46°30′E	Algeria	27°15′N	2°30′E
Western TVD	52°30′N	21°0′E	Bahrain	26°15′N	50°37′W
Southwestern TVD	45°30′N	22°0′E	Djibouti	1°17′N	42°55′E
Southern TVD	45°30′N	64°0′E	Egypt	25°28′N	30°35′E
Central TVD	56°0′N	49°0′E	Iran	31°54′N	54°16′E
Far Eastern TVD	52°20′N	104°0′E	Iraq	33°23′N	43°9′E
Northern Fleet	67°40′N	40°0′E	Israel	32°0′N	34°53′E
Pacific Fleet	43°10′N	132°0′E	Jordan	31°15′N	36°13′E
US[b]			Kuwait	29°13′N	47°58′E
Region I (N)	48°21′N	122°39′W	Lebanon	34°2′N	36°10′E
Region II (N)	32°52′N	117°8′W	Libya	27°39′N	14°16′E
Region II (N)	21°18′N	158°4′W	Mauritania	18°27′N	9°31′W
Region IV (N)	36°56′N	76°17′W	Morocco	32°23′N	6°19′W
Region V (N)	30°12′N	81°52′W	North Yemen	15°28′N	44°13′E
Region I (AF)	44°8′N	103°6′W	Oman	19°52′N	56°3′E
Region I (AF)	64°39′N	147°5′W	Qatar	25°15′N	51°33′E

Region/Alliance/ Country-Deployment	Latitude	Longitude
Region II (AF)	36°14′N	115°2′W
Region II (AF)	21°19′N	157°55′W
Region III (AF)	32°46′N	97°26′W
Region IV (AF)	39°49′N	84°2′W
Region V (AF)	32°38′N	83°35′W
US-Netherlands	52°11′N	5°8′E
US-West Germany	50°1′N	8°34′E
US-UK	52°52′N	1°34′W
US-Portugal	40°9′N	8°28′W
US-Iceland	63°59′N	22°36′W
US-Italy	43°5′N	12°30′E
US-Japan	36°38′N	137°11′E
US-South Korea	37°1′N	127°52′E
US-Philippines	13°35′N	123°16′E
China[c]		
Lanzhou MR	36°4′N	103°52′E
Beijing MR	39°56′N	116°20′E
Shenyang MR	41°50′N	123°25′E
Jinan MR	36°41′N	116°58′E
Nanjing MR	32°4′N	118°47′E
Fuzhou MR	25°59′N	119°11′E
Guangzhou MR	23°2′N	113°8′E
Wuhan MR	30°31′N	114°19′E
Kunming MR	25°8′N	102°35′E
Chengdu MR	30°40′N	104°5′E
North Sea Fleet	36°10′N	120°30′E
East Sea Fleet	31°14′N	121°30′E
South Sea Fleet	21°10′N	110°15′E
Asia/Australasia		
Afghanistan	34°48′N	67°49′E
Saudi Arabia	24°42′N	46°43′E
Somali Republic	6°46′N	47°27′E
South Yemen	15°57′N	48°47′E
Sudan	13°9′N	30°14′E
Syria	34°33′N	38°19′E
Tunisia	34°25′N	8°49′E
UAE	23°1′N	53°55′E
Caribban/Latin America		
Argentina	33°16′S	66°21′W
Bahamas	25°2′N	77°28′W
Belize	17°32′N	88°18′W
Bolivia	17°0′S	65°0′W
Brazil	13°17′S	50°10′W
Chile	33°30′S	70°55′W
Columbia	4°14′N	74°38′W
Costa Rica	8°47′N	83°16′W
Cuba	21°23′N	77°50′W
Dominican Republic	19°12′N	70°30′W
Ecuador	1°12′S	78°34′W
El Salvador	13°26′N	89°3′W
Guatemala	15°28′N	90°24′W
Guyana	4°1′N	58°36′W
Hati	19°8′N	72°0′W
Honduras	14°44′N	86°40′W
Jamaica	17°56′N	76°47′W
Mexico	22°15′N	100°55′W
Nicaragua	11°58′N	85°59′W
Panama	9°4′N	79°22′W
Paraguay	22°35′S	56°49′W
Peru	8°28′S	76°27′W

Region/Alliance/ Country-Deployment	Latitude	Longitude
Australia	23°55′S	132°48′E
Bangladesh	23°46′N	90°23′E
Burma	22°35′N	95°43′E
Cambodia	12°14′N	104°39′E
India	21°5′N	79°2′E
Indonesia	0°7′N	117°28′E
Japan	36°38′N	137°11′E
Laos	18°55′N	102°27′E
Malaysia	3°28′N	102°22′E
Mongolia	46°20′N	102°40′E
Nepal	28°12′N	83°58′E
North Korea	39°50′N	127°30′E
New Zealand	41°19′S	174°48′E
Pakistan	29°34′N	67°50′E
Papua-New Guinea	6°9′S	143°39′E
Philippines	13°35′N	123°16′E
Singapore	1°23′N	103°42′E
South Korea	37°1′N	127°52′E
Sri Lanka	5°59′N	80°19′E
Taiwan	24°11′N	120°39′E
Thailand	13°54′N	100°36′E
Vietnam	21°0′N	105°40′E
NATO		
Belgium	50°54′N	4°29′E
UK	52°52′N	1°34′W
Canada	53°18′N	113°34′W
Canada	43°40′N	79°37′W
Canada-West Germany	50°1′N	8°34′E
Denmark	56°6′N	9°23′E
France	47°3′N	2°22′E
Suriname	4°0′N	55°29′W
Trinidad	10°35′N	61°20′W
Uruguay	32°18′S	55°46′W
Venezuela	7°37′N	66°10′W
Warsaw Pact		
Bulgaria	42°50′N	25°0′E
Czechoslovakia	49°0′N	16°40′E
East Germany	52°28′N	13°24′E
Hungary	47°1′N	19°48′E
Poland	51°45′N	19°30′E
Romania	46°33′N	24°30′E
Sub-Sahara Africa		
Angola	12°48′S	15°45′E
Benin	7°7′N	2°2′E
Botswana	19°58′S	23°25′E
Burkina Faso	12°21′N	1°30′W
Burundi	3°25′S	29°55′E
Cameroon	3°50′N	11°31′E
Cape Verde	16°35′N	24°17′W
Chad	13°14′N	18°18′E
Central African Republic	5°50′N	20°38′E
Congo	0°1′S	15°34′E
Côte d'Ivoire	7°45′N	5°4′W
Ethiopia	9°0′N	38°43′E
Equatorial Guinea	1°54′N	9°48′E
Gabon	0°6′S	11°56′E
Ghana	6°40′N	1°35′W
Guinea	11°20′N	12°17′W
Guinea Bissau	11°53′N	15°39′W
Kenya	0°20′N	37°35′E

Region/Alliance/ Country-Deployment	Latitude	Longitude	Region/Alliance/ Country-Deployment	Latitude	Longitude
France-Djibouti	11°47′N	42°55′E	Madagascar	19°33′S	45°27′E
France-Gabon	0°6′N	11°56′E	Malawi	13°57′S	33°41′E
France-Egypt	25°28′N	30°35′E	Mali	13°25′N	6°16′W
France-Senegal	15°24′N	15°4′W	Mozambique	17°49′S	35°19′E
Greece	39°39′N	22°27′E	Niger	16°57′N	7°59′E
Iceland	63°59′N	22°36′W	Nigeria	8°50′N	7°53′E
Italy	43°5′N	12°30′E	Rwanda	1°58′S	30°8′E
Luxembourg	49°37′N	6°12′E	Senegal	15°24′N	15°4′W
Netherlands	52°11′N	5°8′E	Seychelles	4°40′S	55°30′E
Netherland-Antilles	12°11′N	68°57′W	South Africa	28°37′S	24°44′E
Netherlands-Iceland	63°59′N	22°36′W	Tanzania	6°10′S	35°45′E
Norway	63°27′N	10°56′E	Togo	7°31′N	1°11′E
Portugal	40°9′N	8°28′W	Uganda	2°15′N	32°54′E
Spain	40°17′N	3°43′W	Zaire	2°17′S	23°15′E
Spain-Namibia	22°28′S	17°28′E	Zambia	14°26′S	28°22′E
Turkey	38°42′N	35°30′E	Zimbabwe	19°2′S	30°52′E
West Germany	50°1′N	8°34′E	**Non-Aligned Europe**		
West Germany-UK	52°52′N	1°34′W	Albania	41°6′N	20°5′E
West Germany-Portugal	40°9′N	8°28′W	Austria	48°14′N	14°11′E
West Germany-US	32°46′N	97°26′W	Cyprus	35°9′N	33°16′E
			Finland	64°17′N	27°41′E
			Ireland	53°35′N	7°38′W
			Sweden	63°12′N	14°30′E
			Switzerland	47°11′N	8°12′E
			Yugoslavia	44°27′N	18°43′E

(a) CIS strategic directions (*Napravlenie*), are also known as *Teatr Voennykh Deistvii*, or TVD.
(b) (N): US Navy and Marine Corp aircraft; (AF): US Air Force and US Army aircraft.
(c) MR: Military Region.

APPENDIX B: Charter and Unreported Domestic Traffic Components

This appendix provides additional details on the data used to model the charter and unreported domestic traffic components.

The charter traffic component used six generic aircraft, and the unreported domestic traffic component used three generic aircraft. Nominal capacity and range figures, as well as block time and block fuel equations, are specified below.

			Performance[a]	
Generic Aircraft	**Nominal Capacity**	**Nominal Range (km)**	**Block Fuel (kg)**	**Block Time (hr)**
C1	136	2800	$797 + 2.63D + 5.57\cdot10^{-5}D^2$	$0.349 + 0.00127D$
C2	136	4650	$1600 + 4.18D + 1.27\cdot10^{-4}D^2$	$0.388 + 0.00118D$
C3	136	> 4650	$1110 + 3.41D + 1.11\cdot10^{-4}D^2$	$0.383 + 0.00118D$
C4	172	> 4650	$1720 + 4.75D + 6.43\cdot10^{-5}D^2$	$0.395 + 0.00118D$
C5	336	4650	$3750 + 6.22D + 2.30\cdot10^{-4}D^2$	$0.512 + 0.00115D$
C6	336	> 4650	$5710 + 8.58D + 2.70\cdot10^{-4}D^2$	$0.590 + 0.00112D$
S1	316	6150	$2090 + 5.69D + 7.10\cdot10^{-5}D^2$	$0.464 + 0.00115D$
S2	73	1750	$821 + 2.50D + 9.22\cdot10^{-5}D^2$	$0.480 + 0.00130D$
S3	132	4750	$1740 + 4.45D + 1.89\cdot10^{-4}D^2$	$0.473 + 0.00117D$

(a) *D*: distance flown, in kilometers

The nitrogen oxides (NO_X), carbon monoxide (CO), and unburned hydrocarbons (HC) exhaust emission indices are indexed by altitude band and were derived by weight averaging the calculated fuel flows in the appropriate altitude band and then, using the resultant weighted average fuel flow, linearly interpolating the raw engine emission indices.

	Emission Indices (g/kg)								
	Altitude Band 0-1 km			**Altitude Band 1-9 km**			**Altitude Band 9+ km**		
Generic Aircraft	**NO_X[a]**	**CO**	**HC**	**NO_X**	**CO**	**HC**	**NO_X**	**CO**	**HC**
C1	5.9	18.6	1.0	8.6	3.4	0.1	7.7	7.6	0.4
C2	6.3	4.2	0.7	9.6	2.2	0.5	6.9	2.9	0.6
C3	8.6	8.3	0.8	12.8	2.0	0.2	11.7	2.1	0.2
C4	7.8	12.3	2.6	11.4	3.0	0.5	9.9	4.6	0.8

	Emission Indices (g/kg)								
	Altitude Band 0-1 km			Altitude Band 1-9 km			Altitude Band 9+ km		
Generic Aircraft	NO_x(a)	CO	HC	NO_x	CO	HC	NO_x	CO	HC
C5	9.1	7.0	0.7	15.3	2.6	0.2	7.0	13.3	1.4
C6	5.3	28.8	6.5	13.7	1.2	0.3	7.1	9.4	2.1
S1	7.9	16.3	1.6	12.9	2.5	0.2	10.1	8.6	0.8
S2	8.6	4.9	2.8	14.8	1.7	0.5	11.1	2.3	1.1
S3	3.6	22.0	8.8	5.3	5.6	1.5	4.2	11.6	3.3

(a) NO_x emission index in g of NO_x as NO_2 emitted per kg of fuel.

The table below summarizes the charter traffic network model.

		Revenue Passenger Kilometers ($\times 10^9$)		Generic Aircraft		Block Time (hr)		Block Fuel (kg)	
Route(a)	Great Circle Distance (km)	1990	1992	1990	1992	1990	1992	1990	1992
MAD-LHR	1246	20.15	19.77	C1	C1	1.9	1.9	4157	4157
MAD-FRA	1421	16.95	16.62	C1	C1	2.2	2.2	4645	4645
TFN-LHR	2876	15.04	14.75	C2	C2	3.8	3.8	14,682	14,682
ATH-LHR	2414	13.09	12.84	C1	C1	3.4	3.4	7467	7467
JFK-LHR	5537	9.89	9.70	C3	C3	6.9	6.9	23,384	23,384
ATH-FRA	1806	5.74	5.63	C1	C1	2.6	2.6	5725	5725
YYZ-LHR	5704	4.39	4.15	C3	C3	7.1	7.1	24,158	24,158
LIS-LHR	1564	4.23	8.72	C1	C1	2.3	2.3	5044	5044
IST-FRA	1862	4.15	4.07	C1	C1	2.7	2.7	5883	5883
LHR-MCO	6962	3.81	3.79	C6	C6	8.4	8.4	78,518	78,518
LHR-NYC	5537	3.68	3.67	C6	C6	6.8	6.8	61,489	61,489
FCO-LHR	1444	3.68	3.61	C1	C1	2.2	2.2	4707	4707
LCA-LHR	3275	3.57	3.50	C2	C2	4.2	4.2	16,661	16,661
LHR-MIA	7104	3.04	3.03	C6	C6	8.5	8.5	80,270	80,270
MLA-LHR	2099	2.82	2.77	C1	C1	3.0	3.0	6560	6560
IST-LHR	2511	2.79	2.74	C1	C1	3.5	3.5	7748	7748
LHR-BGR	4937	2.63	2.62	C6	C6	6.1	6.1	54,636	54,636

Route[a]	Great Circle Distance (km)	Revenue Passenger Kilometers (× 10^9)		Generic Aircraft		Block Time (hr)		Block Fuel (kg)	
		1990	1992	1990	1992	1990	1992	1990	1992
BEG-LHR	1699	2.38	2.34	C1	C1	2.5	2.5	5423	5423
YYZ-CDG	6015	2.38	2.33	C3	C3	7.5	7.5	25,624	25,624
ATH-CDG	2097	2.22	2.18	C1	C1	3.0	3.0	6552	6552
TUN-FRA	1471	2.18	2.14	C1	C1	2.2	2.2	4782	4782
JFK-CDG	5830	2.11	2.07	C3	C3	7.3	7.3	24,750	24,750
NBO-FRA	6312	2.08	2.04	C3	C3	7.8	7.8	27,042	27,042
LHR-YYZ	5704	1.66	1.65	C4	C4	7.1	7.1	30,919	30,919
MAD-CDG	1065	1.61	1.58	C1	C1	1.7	1.7	3659	3659
LHR-DTW	6040	1.52	1.52	C6	C6	7.3	7.3	67,376	67,376
ACA-YYZ	3540	1.47	1.46	C4	C4	4.6	4.6	19,353	19,353
TUN-LHR	1830	1.45	1.42	C1	C1	2.7	2.7	5792	5792
IST-CDG	2235	1.43	1.40	C1	C1	3.2	3.2	6949	6949
MEX-LHR	8900	1.32	1.30	C3	C3	10.9	10.9	40,219	40,219
LHR-LAX	8755	1.28	1.27	C6	C6	10.4	10.4	101,507	101,507
TUN-CDG	1488	1.24	1.21	C1	C1	2.2	2.2	4831	4831
VIE-LHR	1270	1.23	1.20	C1	C1	2.0	2.0	4224	4224
BGI-LHR	6747	1.20	1.17	C3	C3	8.3	8.3	29,151	29,151
ACA-NYC	3640	1.15	1.15	C5	C5	4.7	4.7	29,428	29,428
LIS-FRA	1873	1.12	1.09	C1	C1	2.7	2.7	5915	5915
BKK-FRA	8963	1.09	1.07	C3	C3	10.9	10.9	40,560	40,560
FRA-MCO	7616	1.09	1.09	C6	C6	9.1	9.1	86,694	86,694
FRA-NYC	6186	1.08	1.07	C6	C6	7.5	7.5	69,107	69,107
DKR-CDG	4223	1.07	1.05	C2	C2	5.4	5.4	21,531	21,531
SDQ-FRA	7612	1.02	1.00	C3	C3	9.4	9.4	33,475	33,475
CAI-FRA	2918	0.98	0.96	C2	C2	3.8	3.8	14,890	14,890
CDG-YYZ	6015	0.96	0.95	C4	C4	7.5	7.5	32,633	32,633
SDQ-LHR	6979	0.91	0.89	C3	C3	8.6	8.6	30,297	30,297
LHR-CHI	6340	0.87	0.87	C6	C6	7.7	7.7	70,945	70,945
FRA-MIA	7757	0.87	0.87	C6	C6	9.3	9.3	88,497	88,497

		Revenue Passenger Kilometers (× 10^9)		Generic Aircraft		Block Time (hr)		Block Fuel (kg)	
Route[a]	Great Circle Distance (km)	1990	1992	1990	1992	1990	1992	1990	1992
TLV-LHR	3588	0.84	0.82	C2	C2	4.6	4.6	18,242	18,242
TPA-YYZ	1765	0.84	0.83	C4	C4	2.5	2.5	10,310	10,310
FCO-CDG	1102	0.83	0.82	C1	C1	1.8	1.8	3760	3760
BEG-FRA	1053	0.80	0.79	C1	C1	1.7	1.7	3626	3626
FRA-BGR	5583	0.78	0.78	C6	C6	6.8	6.8	62,017	62,017
NBO-CDG	6492	0.73	0.72	C3	C3	8.0	8.0	27,907	27,907
TLV-FRA	2953	0.72	0.70	C2	C2	3.9	3.9	15,061	15,061
CAI-CDG	3208	0.70	0.68	C2	C2	4.2	4.2	16,325	16,325
ZRH-LHR	788	0.68	0.66	C1	C1	1.4	1.4	2902	2902
TLV-CDG	3284	0.67	0.66	C2	C2	4.3	4.3	16,709	16,709
LCA-FRA	2634	0.66	0.65	C1	C1	3.7	3.7	8106	8106
SOF-LHR	2038	0.66	0.64	C1	C1	2.9	2.9	6384	6384
FRA-FLL	7728	0.65	0.65	C6	C6	9.2	9.2	88,122	88,122
ACA-YMX	4000	0.61	0.61	C4	C4	5.1	5.1	21,762	21,762
MEX-FRA	9547	0.60	0.59	C3	C3	11.6	11.6	43,746	43,746
ACA-MCO	2290	0.60	0.59	C5	C5	3.1	3.1	19,198	19,198
MIA-YYZ	1988	0.58	0.58	C4	C4	2.7	2.7	11,423	11,423
POP-YYZ	2781	0.58	0.58	C4	C4	3.7	3.7	15,437	15,437
GIG-FRA	9563	0.57	0.56	C3	C3	11.6	11.6	43,834	43,834
LHR-BOS	5236	0.57	0.56	C6	C6	6.4	6.4	58,029	58,029
LHR-YMX	5217	0.56	0.56	C4	C4	6.6	6.6	28,265	28,265
CMB-FRA	8061	0.54	0.53	C3	C3	9.9	9.9	35,784	35,784
FRA-LHR	654	0.52	0.51	C1	C1	1.2	1.2	2539	2539
KIN-LHR	7513	0.52	0.51	C3	C3	9.2	9.2	32,972	32,972
NRT-NYC	10,826	0.50	0.50	C6	C6	12.7	12.7	130,219	130,219
LHR-EWR	5560	0.50	0.50	C6	C6	6.8	6.8	61,746	61,746
NBO-LHR	6836	0.50	0.49	C3	C3	8.4	8.4	29,590	29,590
FCO-FRA	959	0.50	0.49	C1	C1	1.6	1.6	3369	3369
LHR-FRA	654	0.48	0.47	C1	C1	1.2	1.2	2539	2539

		Revenue Passenger Kilometers (× 10^9)		Generic Aircraft		Block Time (hr)		Block Fuel (kg)	
Route[a]	Great Circle Distance (km)	1990	1992	1990	1992	1990	1992	1990	1992
HAV-FRA	8128	0.47	0.46	C3	C3	10.0	10.0	36,135	36,135
ACA-MIA	2252	0.46	0.46	C5	C5	3.1	3.1	18,919	18,919
CAS-FRA	1301	0.45	0.44	C1	C1	2.0	2.0	4311	4311
CDG-NYC	5830	0.45	0.45	C6	C6	7.1	7.1	64,898	64,898
AMS-NYC	5845	0.45	0.44	C6	C6	7.1	7.1	65,072	65,072
CAS-CDG	854	0.44	0.43	C1	C1	1.4	1.4	3082	3082
CAI-LHR	3528	0.44	0.43	C2	C2	4.5	4.5	17,941	17,941
FRA-DTW	6674	0.44	0.44	C6	C6	8.0	8.0	74,988	74,988
CDG-LHR	346	0.44	0.43	C1	C1	0.8	0.8	1713	1713
LHR-CDG	346	0.44	0.43	C1	C1	0.8	0.8	1713	1713
MLE-FRA	7875	0.44	0.43	C3	C3	9.7	9.7	34,821	34,821
WTD-NYC	1622	0.44	0.43	C5	C5	2.4	2.4	14,442	14,442
SOF-FRA	1395	0.42	0.42	C1	C1	2.1	2.1	4571	4571
CCS-YYZ	3873	0.41	0.41	C4	C4	5.0	5.0	21,091	21,091
BKK-LHR	9540	0.41	0.40	C3	C3	11.6	11.6	43,709	43,709
ACA-DTW	3230	0.39	0.39	C5	C5	4.2	4.2	26,234	26,234
TPA-YMX	2104	0.37	0.37	C4	C4	2.9	2.9	12,007	12,007
AMS-MIA	7437	0.37	0.36	C6	C6	8.9	8.9	84,441	84,441
CDG-MIA	7365	0.36	0.36	C6	C6	8.8	8.8	83,533	83,533
LHR-YVR	7575	0.36	0.36	C4	C4	9.3	9.3	41,406	41,406
FRA-LAX	9317	0.36	0.36	C6	C6	11.0	11.0	109,064	109,064
ACA-FLL	2274	0.35	0.35	C5	C5	3.1	3.1	19,077	19,077
FRA-YYZ	6340	0.33	0.33	C6	C6	7.9	7.9	34,432	34,432
MEX-CDG	9193	0.33	0.32	C3	C3	11.2	11.2	41,809	41,809
CDG-YMX	5526	0.32	0.32	C4	C4	6.9	6.9	29,946	29,946
Total		189.02	185.97						

[a] Although the charter air traffic component network model is nondirectional, routes are defined by origin-destination city or airport pair codes (MDC, 1990). An airport code identifier is unique to each airport. A city code is usually identical to the airport code; however, in cities with more than one airport, there will be one city code for multiple airports.

The unreported domestic traffic component represents air traffic in the Commonwealth of Independent States (CIS - former Soviet Union), Eastern Europe, and China that is not reported by the Official Airline Guide. The table below presents the component's traffic network model. Generic aircraft route assignments did not change from the 1990 scenario to the 1992 scenario.

Route(a)	Great Circle Distance (km)	Available Seat Kilometers ($\times 10^9$) 1990	Available Seat Kilometers ($\times 10^9$) 1992	Generic Aircraft	Block Time (hr)	Block Fuel (kg)
KWE-PEK	1729	27.04	28.47	S2	2.7	5425
CAN-YIN	3717	26.25	27.63	S3	4.8	20,879
HRB-KHG	4108	26.25	27.63	S3	5.3	23,196
IST-AZZ	1744	23.34	24.57	S3	2.5	10,069
BUD-GDN	776	15.56	16.38	S2	1.5	2818
DME-KHV	6135	8.82	9.28	S1	7.5	39,653
DME-TAS	2769	6.07	6.39	S1	3.6	18,386
ALA-DME	3080	5.91	6.22	S1	4.0	20,281
EVN-VKO	1793	5.52	5.81	S3	2.6	10,318
DME-IKT	4190	5.04	5.30	S3	5.4	23,686
DME-SVX	1410	4.92	5.18	S1	2.1	10,253
AER-VKO	1361	3.92	4.12	S1	2.0	9967
MRV-VKO	1314	3.15	3.32	S1	2.0	9692
TBS-VKO	1630	2.94	3.09	S3	2.4	9487
SUI-VKO	1412	2.86	3.01	S1	2.1	10,268
DME-HTA	4727	2.84	2.99	S3	6.0	26,976
SIP-VKO	1200	2.79	2.94	S1	1.8	9018
UUD-VKO	4438	2.67	2.81	S3	5.7	25,196
DME-FRU	2964	2.38	2.50	S3	3.9	16,578
DME-DYU	2946	2.36	2.49	S3	3.9	16,478
BAK-DME	1887	2.27	2.39	S3	2.7	10,805
DME-OVB	2810	2.25	2.37	S3	3.8	15,726
DME-NOZ	3109	1.87	1.97	S3	4.1	17,389
KEJ-VKO	3012	1.81	1.91	S3	4.0	16,843
BAX-DME	2923	1.76	1.85	S3	3.9	16,349

Route(a)	Great Circle Distance (km)	Available Seat Kilometers ($\times 10^9$)		Generic Aircraft	Block Time (hr)	Block Fuel (kg)
		1990	1992			
MMK-SVO	1459	1.75	1.85	S3	2.2	8628
KBP-LED	1068	1.68	1.77	S1	1.7	8250
KIV-VKO	1110	1.56	1.64	S3	1.8	6906
DME-TJM	1883	1.51	1.59	S3	2.7	10,783
BTK-KHV	2371	1.49	1.57	S3	3.2	13,344
LED-SVO	619	1.49	1.57	S2	1.3	2407
ASB-DME	2471	1.49	1.56	S3	3.4	13,881
DME-KGF	2431	1.46	1.54	S3	3.3	13,667
KRR-VKO	1174	1.37	1.44	S3	1.8	7219
DME-OMS	2223	1.34	1.41	S3	3.1	12,559
DME-SGC	2131	1.28	1.35	S3	3.0	12,071
LED-ODS	1495	1.20	1.26	S3	2.2	8809
DME-UFA	1148	1.15	1.21	S3	1.8	7092
KBP-TBS	1428	1.14	1.20	S3	2.1	8474
ROV-VKO	932	1.12	1.18	S3	1.6	6047
ODS-VKO	1110	1.11	1.17	S3	1.8	6906
LED-MMK	1014	1.05	1.10	S3	1.7	6445
KBP-VKO	719	1.01	1.07	S3	1.3	5036
DME-VOG	865	1.01	1.06	S1	1.5	7069
RIX-SVO	826	1.00	1.05	S3	1.4	5539
MCX-VKO	1582	0.95	1.00	S3	2.3	9245
IKT-OVB	1423	0.90	0.94	S3	2.1	8450
EVN-SIP	1002	0.80	0.85	S3	1.6	6383
ODS-RIX	1246	0.78	0.83	S3	1.9	7575
LWO-VKO	1174	0.78	0.83	S1	1.8	8871
ALA-TAS	670	0.73	0.77	S1	1.2	5938
AER-KBP	1026	0.70	0.74	S3	1.7	6501
DME-PEE	1153	0.69	0.73	S3	1.8	7119
BKA-MQF	1370	0.69	0.72	S1	2.0	10,017

		Available Seat Kilometers (× 10^9)				
Route(a)	Great Circle Distance (km)	1990	1992	Generic Aircraft	Block Time (hr)	Block Fuel (kg)
LWO-SIP	877	0.65	0.69	S3	1.5	5782
KBP-SIP	641	0.55	0.58	S3	1.2	4667
SVO-TLL	842	0.52	0.55	S2	1.6	2994
DOK-VKO	834	0.52	0.54	S1	1.4	6887
MSQ-SVO	673	0.52	0.54	S2	1.4	2546
ASF-DME	1230	0.51	0.53	S2	2.1	4040
DME-KUF	831	0.50	0.53	S3	1.4	5565
DME-REN	1202	0.50	0.52	S2	2.0	3964
TAS-UGC	737	0.49	0.52	S3	1.3	5119
BUS-VKO	1546	0.48	0.50	S2	2.5	4913
VKO-VSG	791	0.48	0.50	S3	1.4	5377
DME-KZN	699	0.47	0.49	S1	1.3	6103
DME-ULY	681	0.42	0.44	S1	1.2	5998
KHV-UUS	586	0.40	0.42	S3	1.2	4408
ARH-SVO	971	0.40	0.42	S2	1.7	3338
SCW-SVO	970	0.40	0.42	S2	1.7	3337
SVO-UCT	1240	0.38	0.40	S2	2.1	4066
KBP-KRR	839	0.38	0.40	S1	1.4	6913
KBP-ROV	724	0.38	0.40	S3	1.3	5057
KBP-TLL	1085	0.35	0.37	S2	1.9	3646
DME-RTW	688	0.34	0.36	S1	1.3	6041
HRK-VKO	624	0.31	0.33	S2	1.3	2418
ARH-LED	745	0.31	0.32	S2	1.4	2737
LED-MSQ	693	0.29	0.30	S2	1.4	2599
MSQ-ODS	848	0.26	0.28	S2	1.6	3009
SVO-VNO	201	0.20	0.21	S1	0.7	3242
BAK-EVN	465	0.14	0.15	S2	1.1	2006
SKD-TAS	266	0.10	0.11	S3	0.8	2934
SUI-TBS	629	0.09	0.10	S3	1.2	4609

		Available Seat Kilometers (× 10^9)				
Route(a)	Great Circle Distance (km)	1990	2015	Generic Aircraft	Block Time (hr)	Block Fuel (kg)
SKD-TAS	266	0.10	0.11	S3	0.8	2934
SUI-TBS	629	0.09	0.10	S3	1.2	4609
IEV-OZH	450	0.08	0.08	S3	1.0	3777
ROV-VOG	390	0.08	0.08	S3	0.9	3502
IEV-ODS	434	0.08	0.08	S3	1.0	3702
ASB-MYP	305	0.07	0.07	S3	0.8	3115
BAK-TBS	456	0.07	0.07	S3	1.0	3806
FEG-TAS	225	0.05	0.05	S3	0.7	2748
DYU-SKD	186	0.04	0.04	S3	0.7	2572
ALA-FRU	206	0.03	0.03	S3	0.7	2665
Total		235.64	248.14			

(a) Although the unreported domestic air traffic component network model is nondirectional, routes are defined by origin-destination city or airport pair codes (MDC, 1990). An airport code identifier is unique to each airport. A city code is usually identical to the airport code; however, in cities with more than one airport, there will be one city code for multiple airports.

Cities associated with airport/city codes identified with either the charter or unreported domestic traffic components are shown in the following pages.

CHARTER TRAFFIC COMPONENT CITY CODES

ICAO	LOCALITY
ACA	Acapulco
AKL	Auckland
AMS	Amsterdam
ANC	Anchorage
ANU	Antigua
ARN	Stockholm
ATH	Athens
ATL	Atlanta
AUA	Aruba
AZZ	Ambriz
BAH	Bahrain
BCN	Barcelona
BEL	Belgrade
BGI	Barbados
BGR	Bangor
BKK	Bangkok
BNE	Brisbane
BOG	Bogata
BOM	Bombay
BOS	Boston
BRU	Brussels
BUD	Budapest
BUE	Buenos Aires
CAI	Cairo
CAY	Cayenne
CCS	Caracas
CDG	Paris
CGK	Jakarta
CHC	Christchurch
CLT	Charlotte
CMB	Colombo
CNS	Cairns
CPH	Copenhagen
CTS	Sapporo
CUR	Curacao
CVG	Cincinnati
DEL	Delhi
DFW	Dallas
DHA	Dahrain
DKR	Dakar
DTW	Detroit
DUS	Dusseldorf
DXB	Dubai
EWR	Newark
EZE	Buenos Aires
FBU	Oslo
FCO	Rome
FDF	Martinque
FLL	Ft. Lauderdale
FRA	Frankfort
FUK	Fukuoka
GIG	Rio de Janeiro
GLA	Glasgow
GRU	Sao Paulo
GUM	Guam
GVA	Geneva
HAM	Hamburg
HEL	Helsinki
HKG	Hong Kong
HNL	Honolulu
IAD	Washington, D.C.
IAH	Houston
IST	Istanbul
JED	Jeddah
JFK	New York City
JIB	Djibouti
JKT	Jakarta
KHI	Karachi
KIN	Kingston
KOA	Kona
KUL	Kuala Lumpur
KWI	Kuwait
LAX	Los Angeles
LCA	Larnica
LGW	London
LHR	London
LIM	Lima
LIS	Lisbon
MAD	Madrid
MAN	Manchester
MBJ	Montego Bay
MCO	Orlando
MEL	Melbourne
MEX	Mexico City
MIA	Miami
MLA	Malta
MLE	Male
MNL	Manila
MRS	Marseille
MRU	Maruritius
MSP	Minneapolis
MUC	Munich
MXP	Milan
NAN	Fiji
NBO	Nairobi
NCE	Nice
NGO	Nagoya
NRT	Tokyo
OGG	Kahului
ORD	Chicago
ORY	Paris
OSA	Osaka
OSL	Oslo
PAR	Paris
PDX	Portland
PEK	Beijing
PER	Perth
PHL	Philadelphia
PHX	Phoenix
POP	Puerto Plata
PPT	Papeete
PTP	Pointe a Pitre
RDU	Raleigh/Durham
REC	Recife
ROM	Rome
SAN	San Diego
SCL	Santiago, Chile
SCQ	Santiago, Spain
SDJ	Sendai
SDQ	Santo Domingo
SEA	Seattle
SEL	Seoul
SEZ	Seychelles
SFO	San Francisco
SHA	Shanghai
SIN	Singapore
SJC	San Jose
SJU	San Juan
SNN	Shannon
SOF	Sofia
STL	St. Louis
STN	London
STO	Stockholm
SVO	Moscow
SXM	St. Marten
SYD	Sydney
TFS	Tenerife
TLV	Tel Aviv
TPA	Tampa
TPE	Taipei
TUN	Tunis
TXL	Berlin
UIO	Quito
VIE	Vienna
WAW	Warsaw
WTD	Bahamas
YEG	Edmonton
YMQ	Montreal
YMX	Montreal
YVR	Vancouver
YYC	Calgary
YYZ	Toronto
ZRH	Zurich

UNREPORTED TRAFFIC COMPONENT CITY CODES

ICAO	LOCALITY	ICAO	LOCALITY	ICAO	LOCALITY	ICAO	LOCALITY
AAQ	Anapa, CIS	GME	Gomel, CIS	LED	Leningrad, CIS	SGC	Surgut, CIS
ABA	Abakan, CIS	GOJ	Gorkij, CIS	LWO	Lwow, CIS	SHA	Shanghai, PRC
AER	Adler, CIS	GUW	Guryev, CIS	MCX	Makhachkala, CIS	SIP	Simferopol, CIS
AKX	Aktyubinsk, CIS	HAV	Havana	MMK	Murmansk, CIS	SKD	Samarkand, CIS
ALA	Alma Ata, CIS	HRB	Harbin, PRC	MOW	Moscow, CIS	STW	Stavrapol, CIS
ARH	Arkhangel, CIS	HRK	Kharkov, CIS	MPW	Mariupol, CIS	SUI	Sukhumi, CIS
ASB	Ashkhabad, CIS	HTA	Chita, CIS	MQF	Magnitogorsk, CIS	SVO	Moscow, CIS
ASF	Astrakhan, CIS	IEV	Kiev, CIS	MRV	Nyve Vody, CIS	SVX	Sverdlovsk, CIS
BAK	Baku, CIS	IKT	Irkustk, CIS	MSQ	Minsk, CIS	TAS	Tashkent, CIS
BAX	Barnaul, CIS	KBP	Kiev, CIS	MYP	Mary, CIS	TBS	Tbilisi, CIS
BEG	Belgrade	KEJ	Kemerovo, CIS	NAL	Nalchik,CIS	TJM	Tyumen, CIS
BHK	Bukhara, CIS	KGD	Kaliningrad, CIS	NBC	Naberevnye, CIS	TLL	Tallinn, CIS
BKA	Bykovo, CIS	KGF	Karaganda, CIS	NOZ	Novokuznetsk, CIS	TSE	Tselinograd, CIS
BQT	Brest, CIS	KHE	Kherson, CIS	NSK	Norilisk, CIS	UCT	Ukhta, CIS
BTK	Bratsk, CIS	KHG	Kashi, PRC	ODS	Odessa, CIS	UFA	Ufa, CIS
BUD	Budapest	KHV	Khabarovsk, CIS	OGZ	Ordzhonikidze, CIS	UGC	Urgench, CIS
BUS	Batumi, CIS	KIV	Kishinev, CIS	OMS	Omsk, CIS	ULY	Ulanovsk, CIS
CAN	Guangzhou, PRC	KJA	Krnasjarsk, CIS	OSS	Osh, CIS	UUD	Ulan-ude, CIS
CEK	Chelyabinsk, CIS	KOV	Kokchetav, CIS	OVB	Novosibirsk, CIS	UUS	Sakhalinsk, CIS
CIT	Chimkent, CIS	KRO	Kurgan, CIS	OZH	Zaporozhye, CIS	VIN	Vinnica, CIS
DMB	Dzhambul, CIS	KRR	Krasnodar, CIS	PEE	Perm, CIS	VKO	Moscow, CIS
DME	Moscow, CIS	KRW	Krasnowodsk, CIS	PEK	Beijing, PRC	VNO	Vilnius, CIS
DNK	Dnepropetrovsk, CIS	KSN	Kustanay, CIS	PKC	Petropavlovsk, CIS	VOG	Volgograd, CIS
DOK	Donetsk, CIS	KSQ	Karshi, CIS	PLQ	Palanga, CIS	VSG	Lugansk, CIS
DYU	Dushanbe, CIS	KUF	Kujbysev, CIS	PLX	Semipalatinsk, CIS	VVO	Vladivostok, CIS
EVN	Erevan, CIS	KUN	Kaunas, CIS	REN	Orenburg, CIS	YIN	Yining, PRC
FEG	Fergana, CIS	KUT	Kutaisi, CIS	RIX	Riga, CIS		
FRU	Frunze, CIS	KWE	Guiyang, PRC	ROV	Rostov, CIS		
GDN	Gdansk	KWG	Krivoy Rog, CIS	RTW	Saratov, CIS		
GDX	Magadan, CIS	KZN	Kazan, CIS	SCW	Syktyvkar, CIS		

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Studies relating to environmental emissions database for the military, charter, and non-scheduled traffic for the year 1992 were conducted by McDonnell Douglas Aerospace Transport Aircraft. The report also includes a comparison with a previous emission database for year 1990. Discussions of the methodology used in formulating these databases are provided.

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