NASA Contractor Report 4613

Jet Aircraft Engine Exhaust Emissions Database Development—Year 1990 and 2015 Scenarios

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Prepared for Langley Research Center
under Contract NAS1-19345

July 1994

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TABLES & FIGURES

ACRONYMS

AESA	Atmospheric Effects of Stratospheric Aircraft
ASK	Available seat kilometers
BCAG	Boeing Commercial Aircraft Group
CIS	Commonwealth of Independent States
CO	Carbon monoxide
EI	Emission index
HC	Unburned hydrocarbons
HSCT	High speed civil transport
ICAO	International Civil Aviation Organization
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
US	United States

ACKNOWLEDGEMENT

The work described in this technical report was funded under the National Aeronautics and Space Administration High-speed Systems Research Studies contract NAS1-19345.

Many people at McDonnell Douglas participated in the successful completion of this effort, and they deserve recognition for their contributions. They include Clay Ward, Paul Barr, Richard Van Alstyne, and Z. Harry Landau from Advanced Program Engineering Support; Munir Metwally and Alan Mortlock of the High Speed Civil Transport Program Office; John Morgenstern from Advanced Aircraft Aerodynamics; Andy Grothues from Aircraft Performance; and William Regnier from Propulsion.

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 National Aeronautics and Space Administration's (NASA) High-Speed Research Program Atmospheric Effects of Stratospheric Aircraft (AESA) investigation is an on-going, joint government-academia-industry research effort with multinational contributors. Started in 1990, the program attempts to erase some of the uncertainties surrounding the effects of future supersonic aircraft cruise operations in the stratosphere on ozone levels. Aircraft manufacturers, in particular, are interested because of the potential market for high speed civil transports (HSCT) and the ensuing goal to produce aircraft that are economically viable and satisfy all regulatory and environmental requirements.

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, Reference 2). The design speeds envisioned for HSCT operations and the resultant propulsion requirements will cause the HSCT's efficient cruising altitudes (lower to mid stratosphere) to be significantly higher than present day commercial jet transport operating altitudes (upper troposphere to lower stratosphere). Therefore, legitimate questions to ask are what will be the environmental or atmospheric impact of introducing a new fleet of supersonic transports, operating at relatively higher altitudes than current subsonic aircraft, into commercial airline operations and what standards should be established that define acceptable levels of HSCT emissions? The AESA investigation addresses these questions by evaluating "... the scientific basis for technology directions and for any subsequent policy decisions" (Stolarski and Wesoky, 1993, Reference 38).

The atmospheric impact of HSCT operations in the post year 2005 time frame cannot be assessed without considering projected engine exhaust emissions from other jet (including turboprop) aircraft operations. The HSCT, when it begins operations, will compete for commercial traffic that would otherwise be carried by subsonic aircraft. Consequently, for a given traffic level, engine exhaust emissions released from subsonic jet aircraft operations may be lower when the HSCT is present in commercial operations. At the same time, overall commercial traffic levels will grow between now and when the HSCT begins operations, and some of today's subsonic jet aircraft will be replaced with newer subsonic aircraft that will have incorporated technologies to improve fuel consumption and/or reduced emissions from combustors. In addition to scheduled and unscheduled commercial aircraft operations, which include domestic and international passenger, charter, and cargo services, jet aircraft engine exhaust emissions are generated by general aviation and non-civil (predominantly military) aircraft operations.

McDonnell Douglas Corporation's (MDC) participation in the AESA investigation has included developing jet aircraft engine exhaust emissions databases for the year 1990 and a forecast for the year 2015. These databases form an integral part of the HSCT atmospheric impact assessment. 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, Reference 4). 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, 1990, Reference 33).

Independently, the Boeing Commercial Airplane Group (BCAG), building on an earlier effort that examined engine exhaust emissions at cruise altitude only (BCAG, 1990, Reference 7), examined jet aircraft operations associated with international and domestic scheduled airliner and cargo services traffic (Baughcum, et al., 1993a, Reference 5).

A database for general aviation jet aircraft operations was not developed; however, Balashov and Smith (1992, Reference 3) suggest this component accounts for less than three percent of total jet fuel consumed.

For the year 2015 scenario, MDC and BCAG jointly created a hypothetical HSCT commercial air traffic network consisting of approximately 200 origin-destination city pair routes and associated traffic levels. This network was the result of screening many candidate routes for suitability for HSCT operations. The route selection criteria included great circle distance, difference between flight path distance and great circle distance to avoid over land operations (diversion), percent of flight path distance over land, and potential flight frequency. HSCT operations on this network circa 2015 were modeled for two conceptual vehicles: a Mach 1.6 aircraft (MDC design) and a Mach 2.4 aircraft (BCAG design). Both MDC and BCAG then separately developed several databases by estimating fuel burn and engine exhaust emissions levels for their designs while parametrically varying the NO_x emission index (EI) from $EI(NO_x)=5$ to $EI(NO_x)=15$. Wuebbles, et al. (1993, Reference 44) provides additional information on the overall scenario development process and methodology.

This report addresses the MDC effort to develop the databases for the military, charter, unreported domestic traffic, and Mach 1.6 HSCT components. 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 1990 and 2015 scenarios are provided after which the year 2015 HSCT commercial air traffic network and associated Mach 1.6 HSCT operations on the network are described. The summary examines the emissions level increases due to HSCT operations in the context of global jet aircraft operations and assesses the accuracy of the emissions databases.

ENGINE EXHAUST EMISSIONS DATABASE DEVELOPMENT PROCESS

The emissions database development process is a computer intensive multistep operation that requires several supporting data sets. Hardware platforms employed to construct the 1990 and 2015 scenario databases included both personal (80286 class) and mini (VAX 3080) computers, and software included standard spreadsheet and database applications as well as proprietary FORTRAN programs uniquely suited for processing aircraft emissions data.

Data Requirements

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 AESA 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 1990. 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 1990 and 2015 scenarios.

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 which accurate performance data are available) assigned fuel bum multipliers. A fuel bum multiplier is a weighted-average function, applied by mission category, of aircraft maximum gross

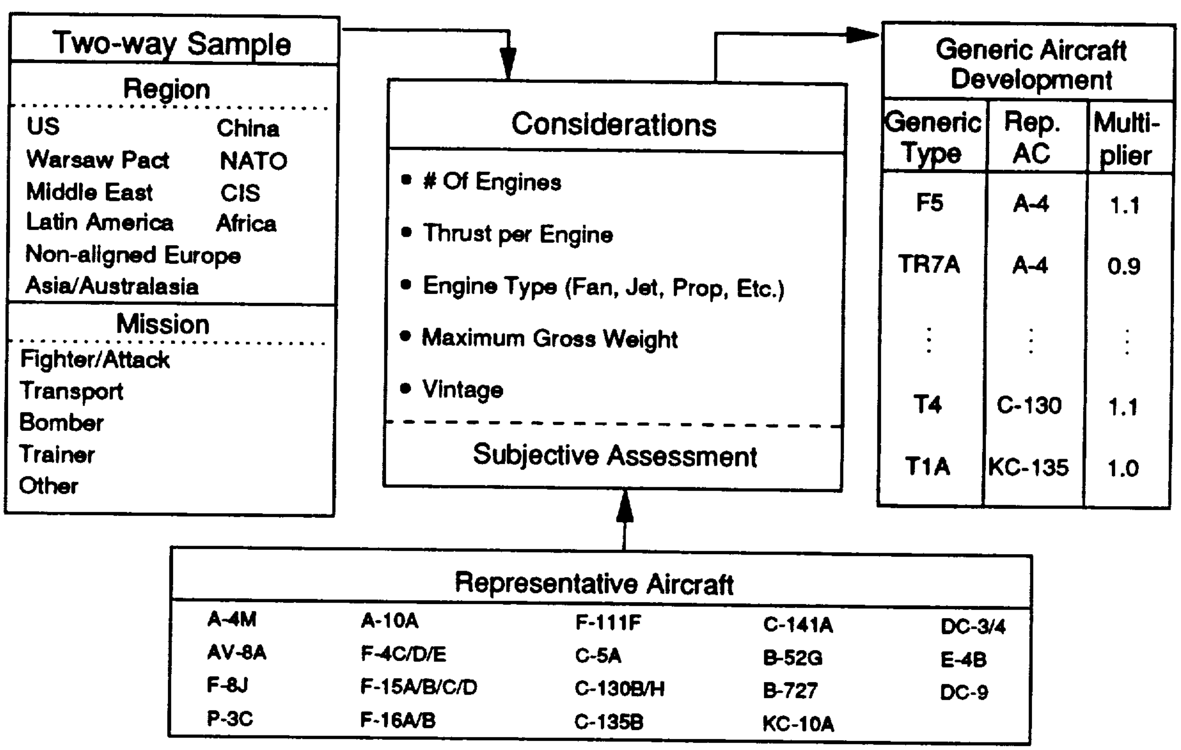

Figure 1. The military component generic aircraft development process. The charter and unreported, domestic traffic components used a similar, but less detailed, approach.

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 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.

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
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.

Substantial previous work (Pace, 1977, Reference 34; Sears, 1978, Reference 36; ICAO, 1989, Reference 19) 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. 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.

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). For a specific engine application, EI(CO) and EI(HC) decrease as a function of engine power setting as Figure 2 shows for several engines 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 modern day production engines. This tendency is likely due to pressure ratio, surface-to-volume ratio, and air loading scale effects (Munt and Danielson, 1976, Reference 29).

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, but, for supersonic aircraft, the highest EI(NO_X) occurs during the supersonic cruise flight phase. For a given engine, EI(NO_X) increases with power setting as depicted in Figure 3, 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, Reference 29).

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. At the higher altitudes in the stratosphere where future supersonic aircraft will cruise, NO_X emissions may actually contribute to the depletion of the stratospheric ozone layer which protects the Earth from harmful ultraviolet radiation (Crayston, 1992, Reference 11; Thame, 1992, Reference 39; Bahr, 1992, Reference 2).

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. Each great circle flight segment

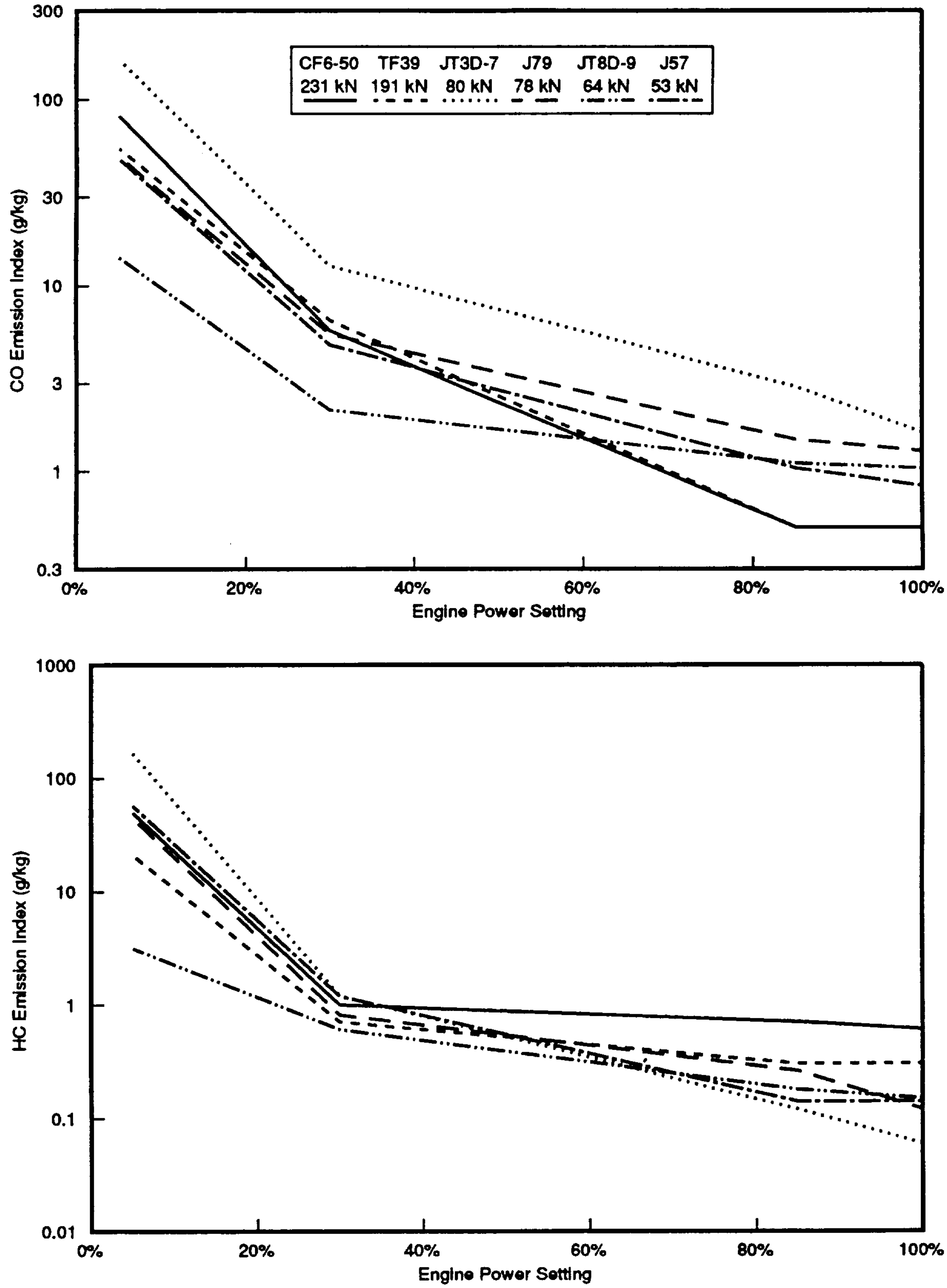

Figure 2. CO (upper panel) and HC (lower panel) emission indices decrease as engine power setting (percent of takeoff rated thrust) increases. Engine rated thrust is expressed in kilonewtons.

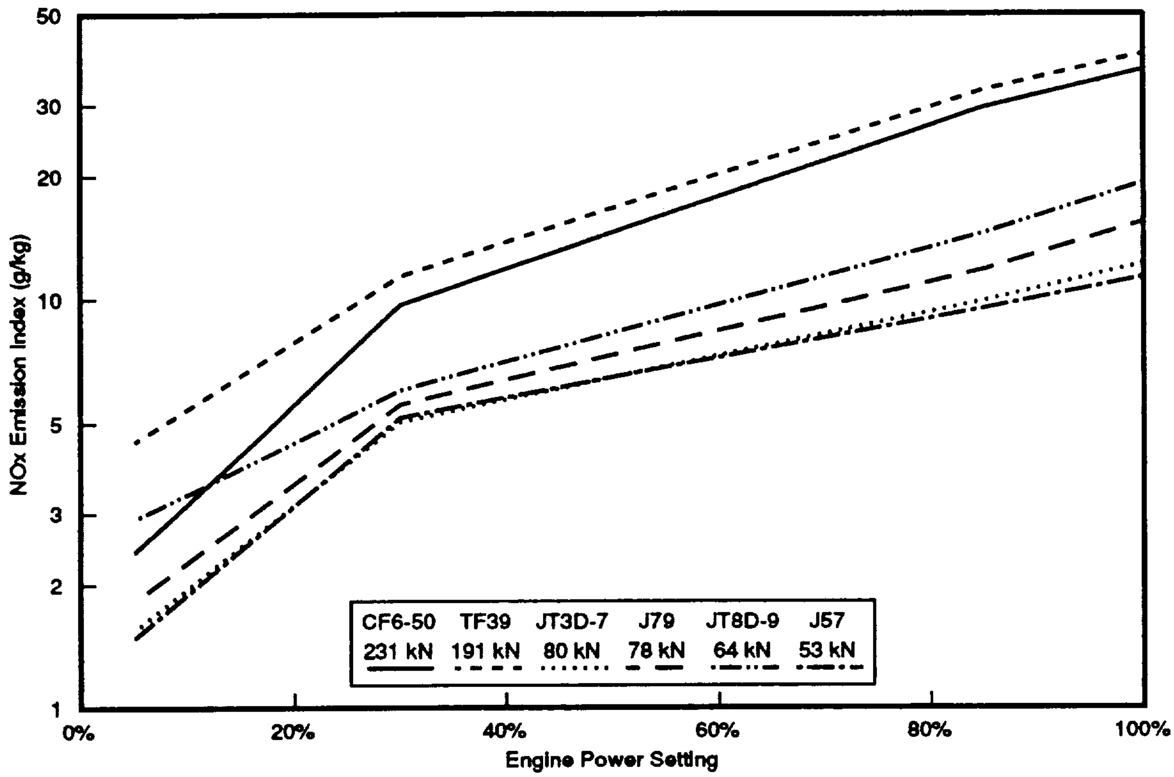

Figure 3. NO_x emission indices increase as engine power setting (percent of rated thrust) increases. Engine rated thrust is expressed in kilonewtons.

traverses one or more grid cells. The fuel consumed on any flight segment is linearly allocated, 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 1990 and 2015 scenarios. 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

Latitude	Longitude	Distance (km)	Cumulative 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 for the 1990 scenario 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.

Countries were initially grouped into regions or military alliances to support generic aircraft development, aircraft basing, and the forecast of the 2015 military aircraft inventory. These groups include the US, CIS, China, North Atlantic Treaty Organization (NATO) excluding US, former Warsaw Pact excluding CIS, non-aligned Europe, Caribbean and Latin America, Asia and Australasia, Middle East and North Africa, and Sub-Sahara Africa. Typically, 50% of the countries in a region or alliance group account for 90% of the group's aircraft. Aircraft were inventoried by owning country, not by deployment location.

1990

In 1990, 138 countries owned approximately 60,000 fixed-wing military aircraft (Air Force, 1991, Reference 1; International Institute for Strategic Studies, 1989, Reference 21; International Media Corporation, 1990, Reference 22). Together, the US, CIS, and China accounted for over 50% of the total fleet. Table 3 summarizes the 1990 inventory of military aircraft, and Figure 4 shows the distribution of aircraft among the top countries in terms of numbers of aircraft. The

Table 3. 1990 Inventory of Military Aircraft[a]

	Mission						
	Fighter/ Attack	**Transport[b]**	**Bomber**	**Trainer**	**Other**	**Total**	**Percent**
CIS	7269	2253	985	1000	1232	12,739	21.3%
US	4853	2017	372	2602	1805	11,649	19.5%
Asia/Australasia	4281	1082	90	1463	519	7435	12.4%
NATO	3240	1218	18	1717	800	6993	11.7%
China[c]	5100	213	600	0	304	6217	10.4%
Middle East/North Africa	3706	682	38	1270	161	5857	9.8%
Caribbean/Latin America	1125	865	46	602	193	2831	4.7%
Warsaw Pact	1891	207	0	328	137	2563	4.3%
Sub-Sahara Africa	884	471	0	256	183	1794	3.0%
Non-Aligned Europe	1068	70	0	404	161	1703	2.8%
Global Total	33,417	9078	2149	9642	5495	59,781	100%
Mission Distribution	55.9%	15.2%	3.6%	16.1%	9.2%	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.

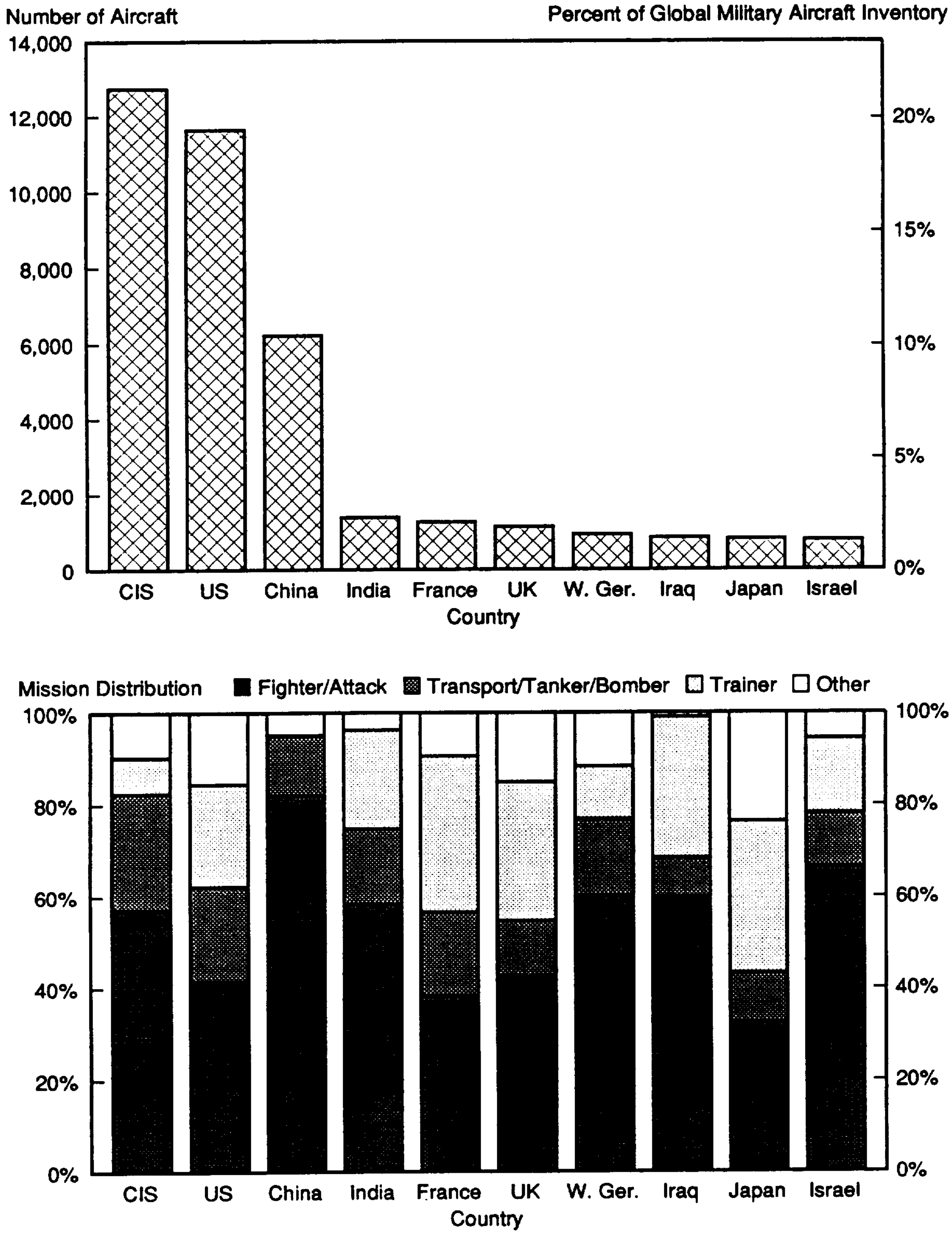

Figure 4. Distribution of 1990 military aircraft. Upper panel shows total aircraft possessed by top ten countries. Bottom panel shows distribution of aircraft by mission type.

full inventory of 1990 military aircraft, by country, is at Appendix A.

2015

Any 25-year forecast of global military aircraft inventories is speculative at best, especially in light of recent world events. Historical data analysis is of little value in analyzing post-Cold War defense trends, particularly for the countries possessing the bulk of military aircraft. Several factors can influence future military aircraft inventories for any country. These include the military's changing function in society, e.g. traditional national security and defense against sovereign threats, humanitarian relief efforts, drug trade interdiction, etc.; current force structure; regional and/or global tensions and projected threat environment; defense spending levels; peacetime and wartime attrition rates; tempo of operations; direct inventory reductions due to retiring and salvaging aircraft, selling aircraft, or placing aircraft in mothballs; and direct inventory buildups from purchasing new or used aircraft or removing aircraft from mothballs. The magnitude and importance of these factors varies from country-to-country, among mission categories, and by specific aircraft type.

No single data source offers a sufficiently long-range, globally integrated forecast of military aircraft inventories that considers all the above factors and is sensitive to the diverse types of aircraft included in the broad mission categories. Therefore, the forecast of the 2015 scenario military aircraft inventory was based on a qualitative assessment and subsequent subjective merger of themes and data collected from a variety of sources (Lorell, 1992, Reference 24; Nation, 1990, 1991, 1992, References 30,31,32; Morrocco, 1992, Reference 28; Fulghum, 1992, Reference 18; Correll, 1991a, 1991b, References 9,10; Reed, et al., 1992, Reference 35; Forecast International, 1992, Reference 17). Several themes appear consistently among the data sources:

- the US, other NATO countries, and the CIS will see reductions on the order of 30% in military aircraft force levels by the year 2000,
- fewer new military aircraft programs will ever reach the production phase and those that do will have experienced substantial schedule slips from original plans, and
- while global war is now relatively unlikely, regional conflicts will continue to occur and may even increase in frequency.

Two assumptions underpinned the forecast. First, the distribution of aircraft, by mission, within a region, alliance, or country group will not change significantly from 1990 to 2015. Similarly, the second underlying assumption is that the distribution of aircraft by region, alliance, or country group will not change drastically.

Table 4 summarizes the 2015 scenario military aircraft inventory by group and mission category. Some differences exist between the 1990 scenario and 2015 scenario inventories. For the 2015 scenario, the bomber, US and CIS tanker, and transport mission categories were combined since, in 1990, both bombers and tankers each accounted for less than four percent of

Table 4. Forecast of Year 2015 Military Aircraft Inventory

	Mission					
	Fighter/ Attack	Transport/ Bomber[a]	Trainer	Other	Total	Percent
US	3600	2000	2000	1500	9100	17.6%
Europe	4700	1400	2000	900	9000	17.4%
CIS	4700	2400	1000	700	8800	17.1%
Asia/Australasia	4700	1300	1700	500	8200	15.9%
Middle East/North Africa	3900	700	1300	200	6100	11.8%
China[b]	4500	800	0	300	5600	10.9%
Latin America	1200	900	600	200	2900	5.6%
Sub-Sahara Africa	900	500	300	200	1900	3.7%
Global Total	28,200	10,000	8900	4500	51,600	100%
Mission Distribution	54.7%	19.3%	17.3%	8.7%	100%	

[a] Aerial refueling (tanker) aircraft included in the transport/bomber category.
[b] China's trainer aircraft included in the fighter/attack aircraft category.

the global military aircraft fleet. In addition, the NATO, non-aligned Europe, and Warsaw Pact groups were consolidated into a single regional group called Europe.

Military Generic Aircraft

Appendix A identifies the generic aircraft used in the 1990 and 2015 scenarios. 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.

The generic aircraft used in the 2015 scenario were similar to the 1990 scenario generic aircraft. The 2015 scenario generic aircraft reflect improvements in fuel consumption. Figure 5 shows the historical trend in turbine engine thrust specific fuel consumption rates (Koff, 1991, Reference 23). Improvements in fuel consumption generally appear first in commercial engine applications but eventually are incorporated in military engines as well. If the historical trend continues, thrust specific fuel consumption rate reductions on the order of 20% to 25% are possible by the year 2015. The results of this trend will be mitigated somewhat by any increased performance demands of future military aircraft; therefore, the 2015 scenario generic aircraft fuel consumption rates reflect a 12% improvement over their 1990 generic aircraft counterparts.

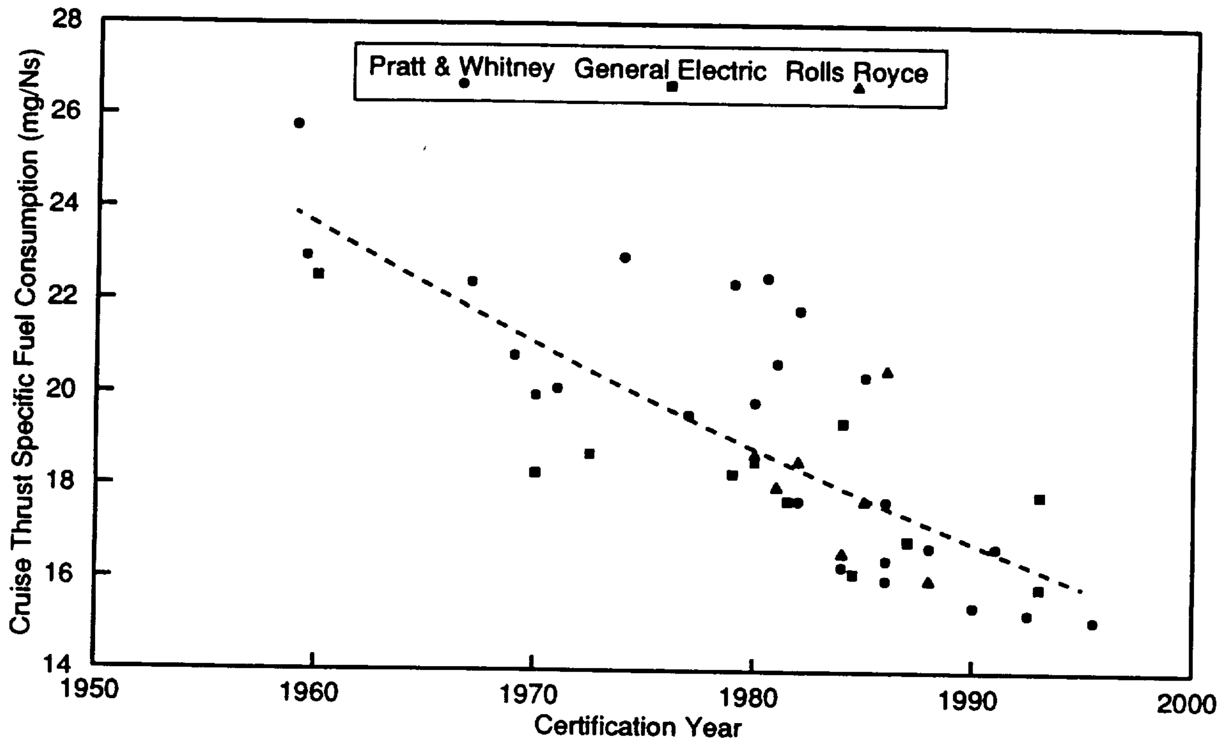

Figure 5. The trend in thrust specific fuel consumption (TSFC) shows a 20% to 25% improvement in fuel efficiency over the past 25 years.

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 1990 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, Reference 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.

For the 2015 scenario, countries within a region were grouped into subregions based on geographic proximity. Next, the forecast 2015 military aircraft inventory for the region, as represented by generic aircraft, was allocated to the subregions by mission type. The allocation was approximate and based on the distribution of aircraft, by mission type, within the 1990 inventory. Subsequently, the subregion's allocated generic aircraft were based at one or two locations within each subregion.

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 1990, the former Soviet Union located its military assets among eight entities called fleets, front, or strategic directions (International Institute for Strategic Studies, 1989, Reference 21). 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 6. Each region's allocation of aircraft, by mission type, approximates the actual

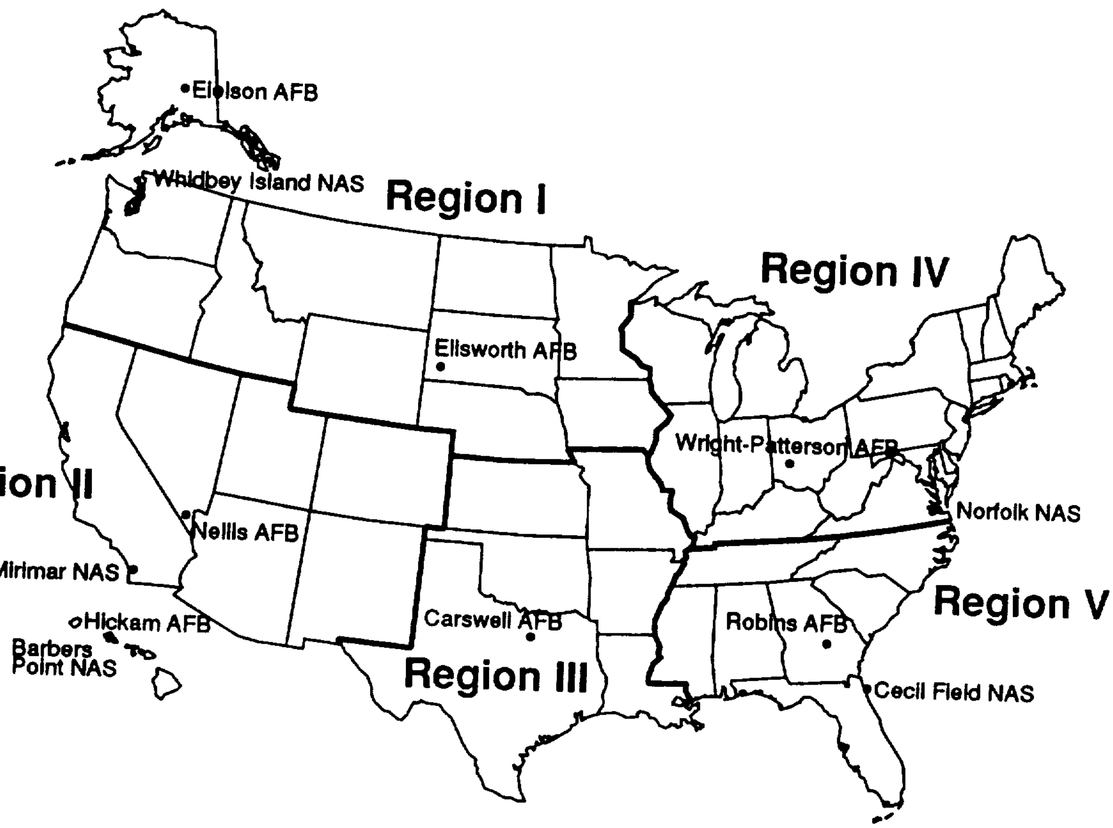

Figure 6. Generic aircraft representing the US fleet were based at several Air Force and Navy facilities. The allocation of aircraft was based on the distribution of military forces among the regions.

mix of operational aircraft assigned to military bases contained in the region (Air Force, 1991, Reference 1; MILAV News, 1991, Reference 27). Some US Air Force and Navy aircraft were located in foreign territories to reflect unit deployments.

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, References 41,42). 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, either a landing and subsequent return to the origin, a period of combat training maneuvers

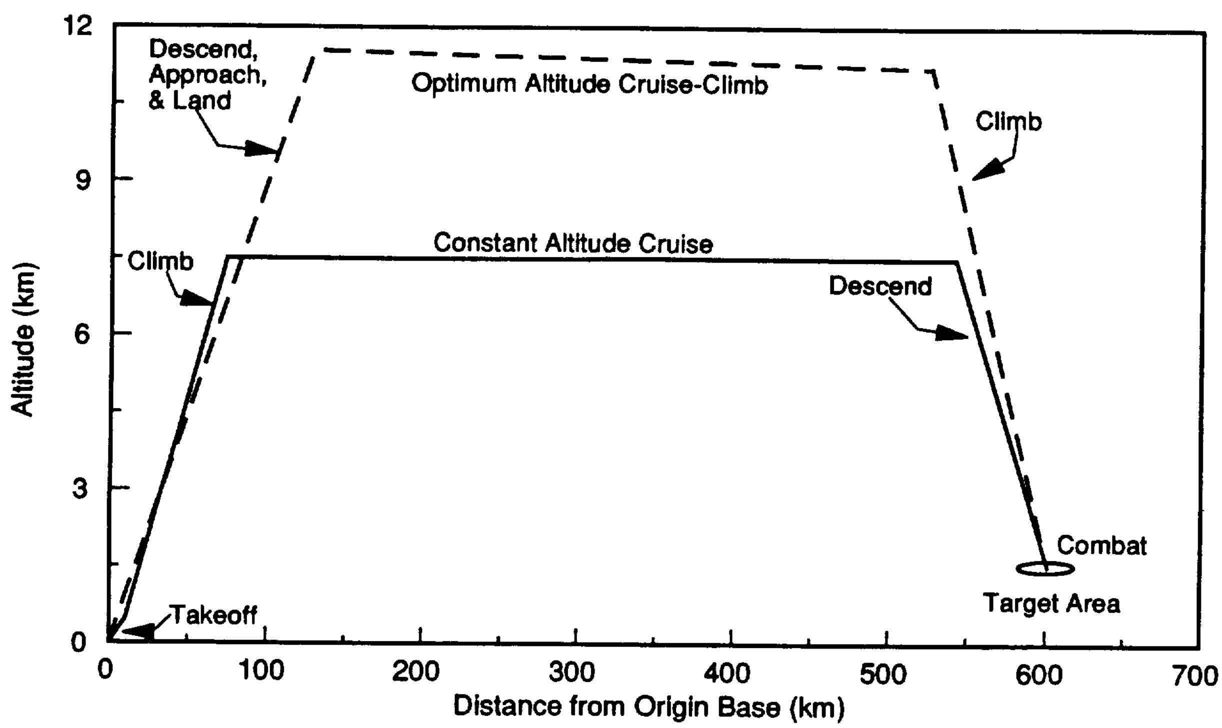

Figure 7. Example mission profile for a fighter/attack generic aircraft. All military air traffic component missions begin and end at the same location.

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 7 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, Reference 43). 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, Reference 43). 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 5. 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 1989-1990 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

* This inventory count reflects a 60%/40% split of the 1851 total CIS Air Force transport aircraft between generic aircraft types T3AFA and T3AFB.
# Generic aircraft mission lengths are included in Appendix A.

Table 6 summarizes the utilization rates, by region and mission, used for the military aircraft operations emissions database.

Table 6. 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 7 summarizes the military component fuel burn and engine exhaust emissions estimates by altitude band for the 1990 scenario. The 2015 scenario results are depicted in Table 8.

Peak fuel burn for the 1990 scenario occurs in the 10-11 km altitude band while it occurs in the 11-12 km altitude band for the 2015 scenario. 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 EI(CO) and EI(HC) spikes in the 14-15 km altitude band are anomalies. The likely causes are the few number of generic aircraft operating in this altitude band, the relatively high emission indices for those aircraft that do operate in this band, and the weighted-average fuel flow methodology used to derive a single emission index by altitude band for each exhaust constituent.

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

Table 8. 2015 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	2.29	11.1%	28.74	19.5%	20.35	5.0%	3.76	2.0%	12.57	8.90	1.64
1-2	1.35	17.7%	8.84	25.5%	17.17	9.3%	1.33	2.8%	6.54	12.71	0.99
2-3	0.69	21.0%	5.18	29.0%	6.89	11.0%	1.37	3.5%	7.53	10.02	2.00
3-4	0.53	23.6%	3.62	31.4%	5.98	12.4%	1.04	4.1%	6.83	11.26	1.95
4-5	0.35	25.3%	2.45	33.1%	5.20	13.7%	0.80	4.5%	7.11	15.07	2.30
5-6	0.34	26.9%	2.44	34.8%	5.16	15.0%	0.79	4.9%	7.11	15.05	2.30
6-7	1.14	32.5%	5.19	38.3%	19.78	19.9%	1.03	5.5%	4.56	17.36	0.91
7-8	1.53	39.9%	8.61	44.1%	26.12	26.3%	3.09	7.1%	5.64	17.10	2.02
8-9	0.92	44.4%	6.57	48.6%	17.74	30.7%	4.53	9.6%	7.12	19.22	4.91
9-10	2.11	54.6%	15.92	59.4%	43.21	41.3%	8.83	14.4%	7.55	20.48	4.19
10-11	3.06	69.5%	20.51	73.3%	68.19	58.1%	33.71	32.6%	6.71	22.30	11.02
11-12	3.18	85.0%	18.19	85.6%	87.43	79.7%	64.04	67.3%	5.72	27.51	20.15
12-13	2.10	95.1%	14.11	95.2%	52.50	92.6%	33.52	85.4%	6.73	25.04	15.99
13-14	0.62	98.1%	4.71	98.4%	15.60	96.5%	13.54	92.8%	7.61	25.24	21.91
14-15	0.22	99.2%	1.08	99.1%	10.87	99.2%	10.70	98.5%	5.00	50.32	49.55
15-16	0.17	100.0%	1.33	100.0%	3.38	100.0%	2.69	100.0%	8.01	20.42	16.27
Global Total	20.58		147.49		405.57		184.77		7.17	19.71	8.98

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, 1990, Reference 33); 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 8 (MDC, 1991, Reference 26). 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 1990 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, Reference 37; ICAO, 1991, Reference 20; Belet and Colomb de Daunant, 1991, Reference 8; CTI, 1991, Reference 12). 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 9 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 1990 charter air traffic network model. The 1990 charter air traffic, 189 billion RPK, was apportioned among these top 100 origin-destination city pairs.

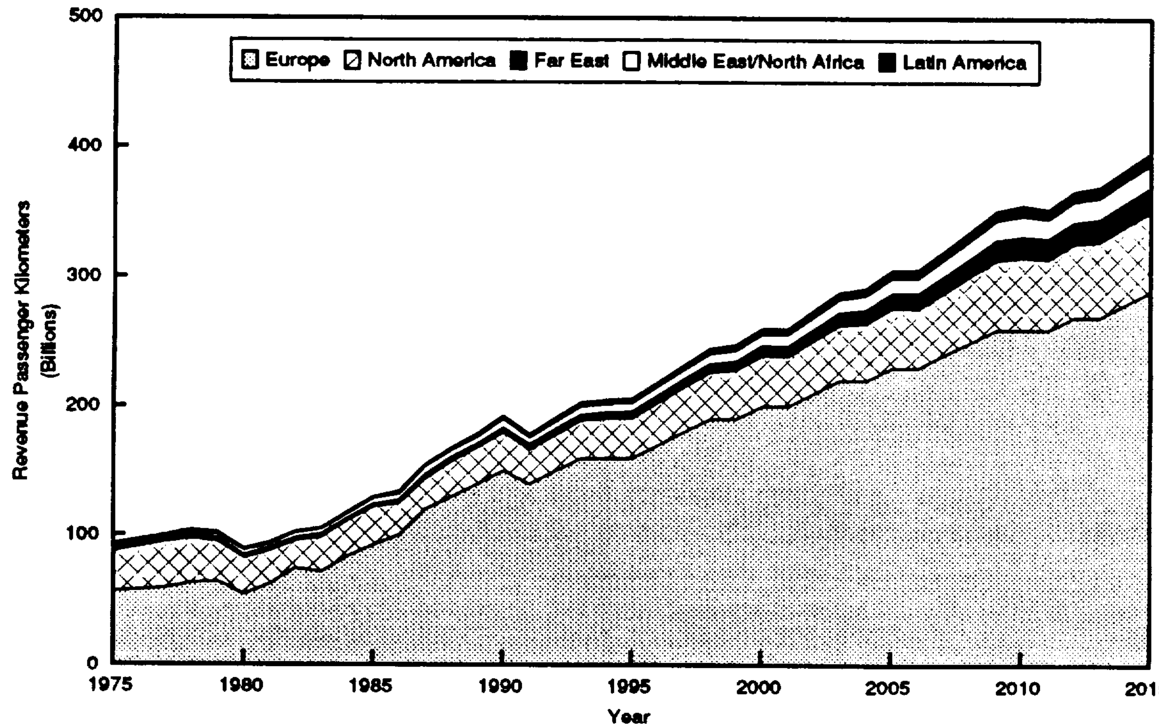

Figure 8. History and forecast of charter traffic growth. Europe and North America account for well over 90% of the traffic. Regions are from where traffic originates.

For the 2015 scenario, the forecast charter traffic of 392 billion RPK in 2015 was similarly apportioned among the top 100 origin-destination city pairs.

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 1990 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 236 billion ASK, consisting of 208 billion ASK from the CIS, 19 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 1990 scenario.

A 2.7% annual compound growth rate was applied to this air traffic component to yield a year 2015 forecast air traffic level of 449 billion ASK. The 2015 scenario air traffic network model was constructed by apportioning the 449 billion ASK among the 91 routes.

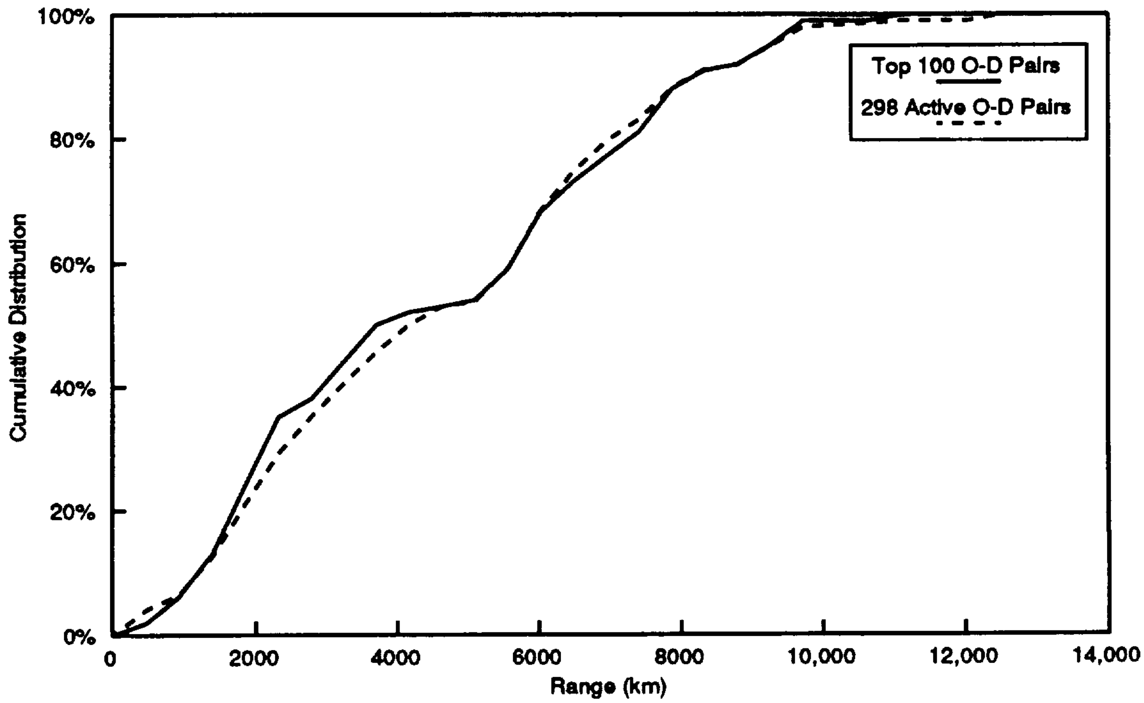

Figure 9. Cumulative distribution of ranges between selected origin-destination city pairs that have a positive 1990 charter air traffic level. Top 100 city pairs formed the basis for the charter network.

Charter and Unreported Domestic Traffic Components Generic Aircraft and Emission Indices

The 1990 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, Reference 8), shown in Figure 10, provides a representative sample of this aircraft mix. Similarly, Figure 11 indicates the relative distribution of aircraft types in the 1990 Aeroflot fleet that served domestic traffic needs.

Six generic aircraft were used for the charter component to model fuel burn and engine exhaust emissions for both the 1990 and 2015 scenarios; the unreported domestic traffic component employed three generic aircraft. A charter route's range and capacity requirements dictated the generic aircraft assigned to the route. 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

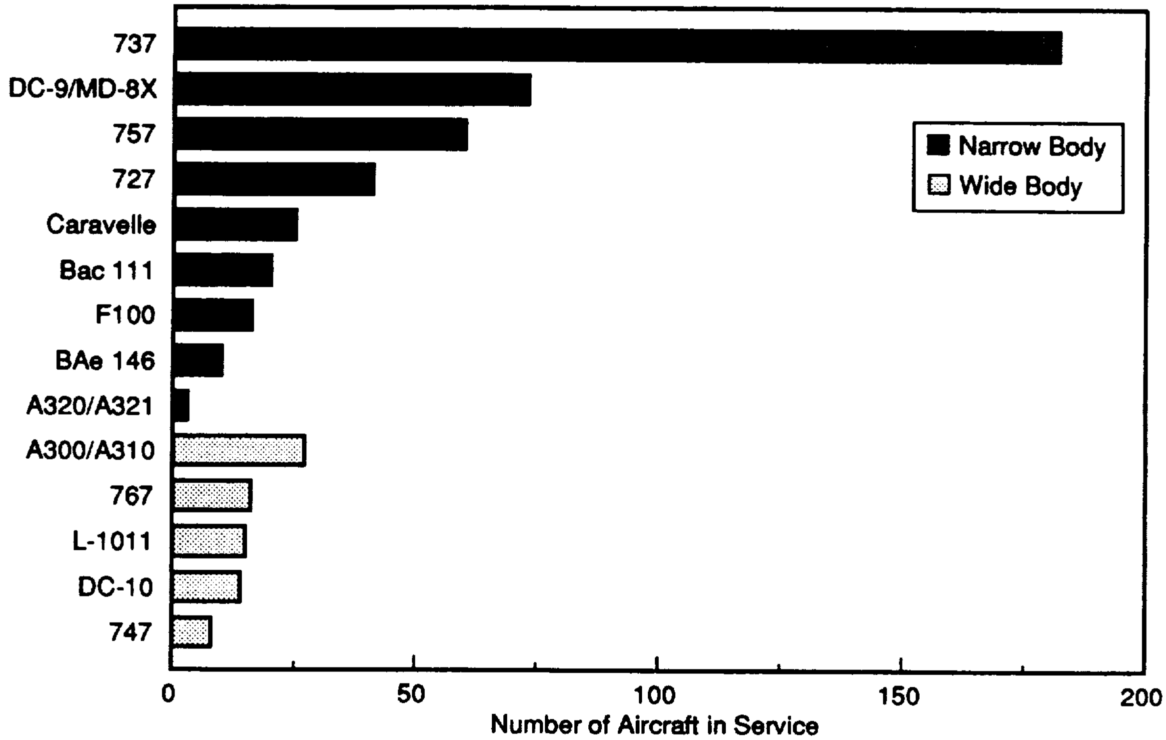

Figure 10. Distribution of aircraft types in the 1990 European charter traffic fleet. The generic aircraft used to model charter traffic fuel burn and emissions reflect characteristics of these aircraft.

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 2015 scenario estimates. Historically, charter operators provide their services with equipment retired from service by the scheduled airline carriers. While there will be some charter fleet mix changes from 1990 to 2015 (1990 vintage equipment will replace some of the older charter aircraft), it is expected that the impact of these changes on global emissions will be relatively minor, especially when the fraction of total air traffic that charter traffic represents is considered. Forecasting changes to the unreported domestic traffic component aircraft fleet is difficult because of large uncertainties with respect to the existing fleet composition.

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

Flight Profiles

A single generic aircraft type carries all annual traffic on each great circle route in the charter and unreported domestic traffic components network models. 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

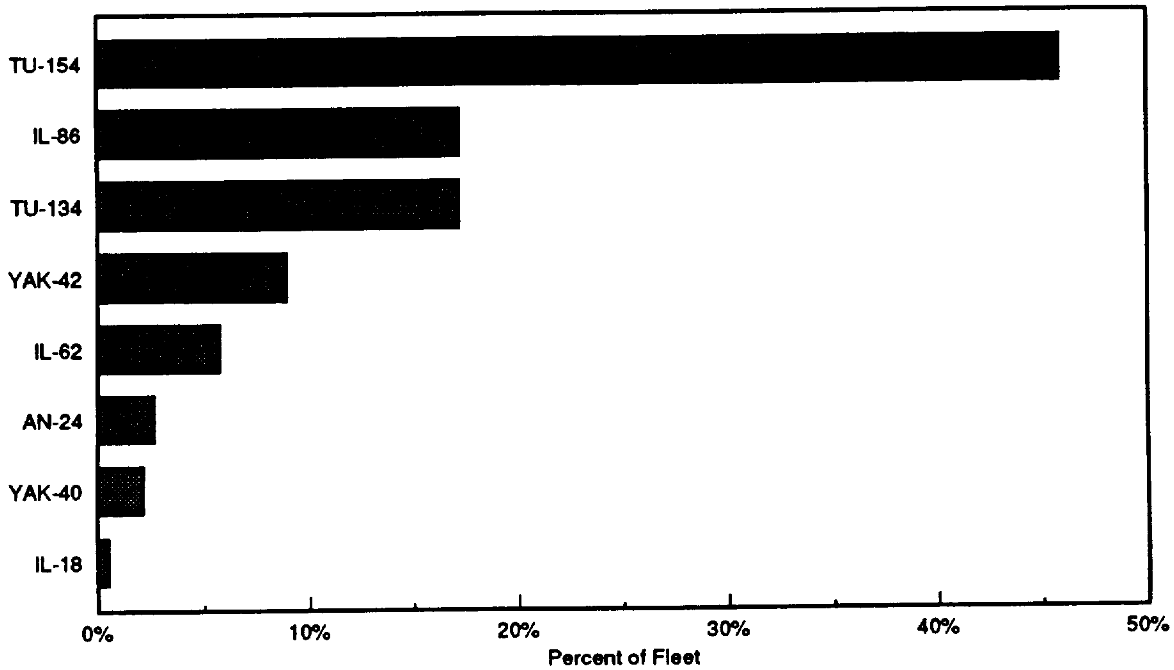

Figure 11. Relative distribution of aircraft included in Aeroflot's 1990 domestic traffic fleet. Generic aircraft with similar characteristic were used to develop fuel burn and emission estimates.

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 operations to 37,000 feet for long range, wide-body operations. All cruise fuel was linearly allocated between the initial and final cruise altitudes.

Fuel Burn and Exhaust Emissions Estimates

Table 9 and Table 10 contain the 1990 scenario and 2015 scenario fuel burn and engine exhaust emission estimates, respectively, for the combined charter and unreported domestic traffic components, arranged by altitude band.

Peak fuel burn and exhaust emissions levels for both the 1990 and 2015 scenarios occur in the 10-11 km altitude band. Both CO and HC emissions have small secondary peaks (5% and 9% of peak values, respectively) in the 0-1 km altitude band.

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	.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. 2015 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	0.78	2.7%	4.75	2.2%	13.15	5.7%	2.17	4.3%	6.11	16.89	2.79
1-2	0.78	5.3%	7.86	5.8%	2.34	6.8%	0.30	4.9%	10.10	3.01	0.38
2-3	0.78	8.0%	7.85	9.5%	2.33	7.8%	0.30	5.5%	10.11	3.01	0.38
3-4	0.78	10.6%	7.84	13.1%	2.33	8.8%	0.30	6.1%	10.11	3.01	0.38
4-5	0.85	13.5%	8.45	17.0%	2.58	9.9%	0.30	6.7%	9.97	3.04	0.36
5-6	0.76	16.1%	7.71	20.5%	2.29	10.9%	0.31	7.3%	10.15	3.01	0.40
6-7	0.76	18.7%	7.66	24.1%	2.28	11.9%	0.31	7.9%	10.13	3.02	0.41
7-8	0.72	21.1%	7.37	27.5%	2.14	12.9%	0.28	8.5%	10.21	2.96	0.38
8-9	0.72	23.6%	7.34	30.9%	2.13	13.8%	0.28	9.0%	10.21	2.96	0.38
9-10	5.12	41.1%	42.01	50.3%	33.54	28.5%	4.50	18.0%	8.20	6.55	0.88
10-11	14.16	89.5%	77.56	86.2%	139.81	89.6%	38.57	94.7%	5.48	9.87	2.72
11-12	2.37	97.6%	22.74	96.7%	17.71	97.3%	2.10	98.9%	9.59	7.47	0.89
12-13	0.71	100.0%	7.17	100.0%	6.10	100.0%	0.57	100.0%	10.10	8.60	0.80
Global Total	29.28		216.29		228.73		50.26		7.39	7.81	1.72

SCHEDULED AIR TRAFFIC COMPONENT EMISSIONS USING THE MACH 1.6 HSCT CONCEPTUAL AIRCRAFT

The development of global fuel burn and engine exhaust emissions levels estimates from a conceptual Mach 1.6 HSCT operating on a year 2015 supersonic commercial scheduled air traffic network is described in this section. The air traffic network model is described, and some characteristics of the conceptual supersonic aircraft are defined.

HSCT Scheduled Air Traffic Network Model

MDC and BCAG jointly developed the supersonic scheduled air traffic network model for the year 2015 scenario. The routes and traffic levels composing the 1990 scheduled airliner traffic network were the starting point for creating the supersonic traffic network model (OAG, 1990, Reference 33). The ground rules used to select year 2015 supersonic network routes from the year 1990 routes included (Wuebbles, et al., 1993, Reference 44):

- routing over land must not exceed 50% of the total distance;
- flight distance must be greater than 3704 km (2000 nm);
- supersonic flight over land is not permitted (supersonic flight corridors which would permit supersonic operations over land in designated remote and/or low population areas were not considered in this analysis); and,
- the added distance from diverting flight paths to avoid flying over land must not exceed 20% of the great circle distance.

Candidate routes unable to support at least one HSCT flight per day were eliminated from consideration.

Two hundred routes were selected for the supersonic network to support a nominal fleet of 500 Mach 2.4 HSCT. Year 2015 traffic levels for each of the 200 routes were forecasted by applying regional growth factors to the 1990 traffic levels. The forecast assumed annual regional growth rates ranging from approximately 4.5% for the North America-Europe region to 9% for the North America-Asia region. Appendix C describes the 200 routes which are identified as origin-destination city (or airport) pairs. In the year 2015, a fleet of 594 Mach 1.6 HSCT with a 300 seat capacity would serve 387,000 passengers/day and generate 1337 billion ASK of aircraft traffic to satisfy passenger demand. Wuebbles, et al. (1993, Reference 44) provides additional details on the development of the network.

Aircraft Definition and Engine Exhaust Emission Indices

Previous Mach 1.6 design optimization studies developed the aircraft configuration shown in Figure 12. The 300 seat aircraft has a design range of 9260 km (5000 nm) when flown a maximum of 15% over land at subsonic speeds. Pratt & Whitney provided performance and emissions data for a Mach 1.6 two spool, non-augmented mixed flow turbofan engine employing low NO_x combustor technology (United Technologies, 1992, Reference 40). Predicted engine

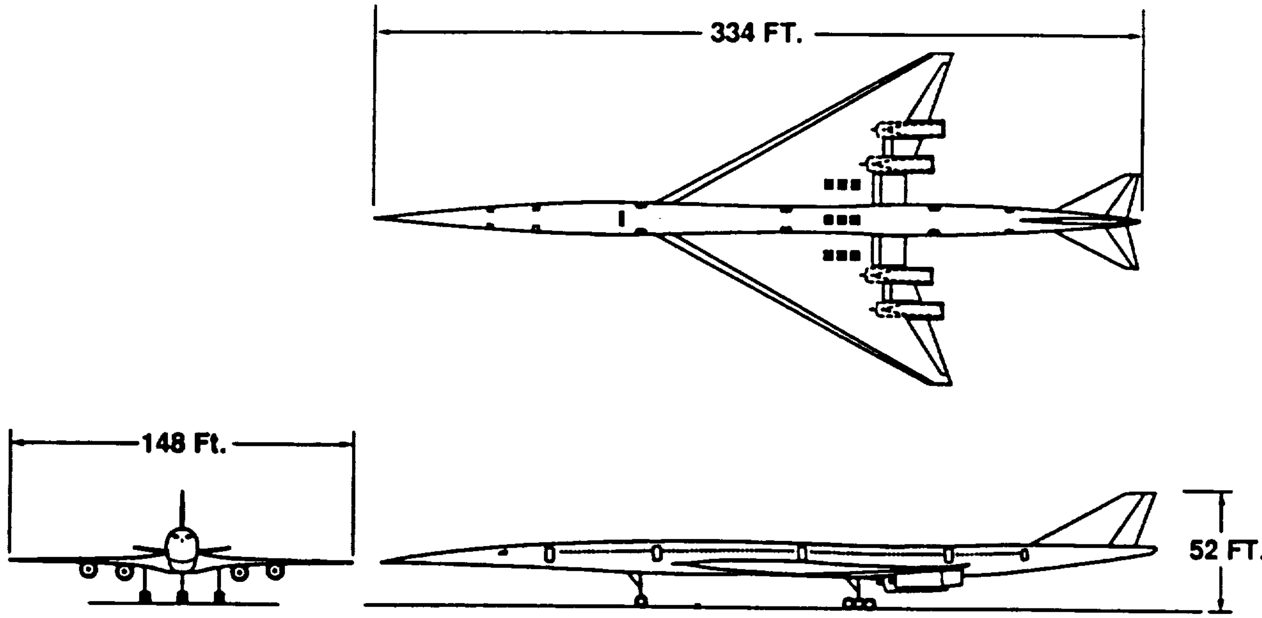

Figure 12. Configuration for a Mach 1.6 HSCT from design optimization studies at McDonnell Douglas.

and airframe performance, adjusted for engine installation and operational effects, were integrated with the airframe design to determine the final HSCT performance predictions.

Three cases representing different nominal EI(NO_x) at supersonic cruise altitudes were examined: EI(NO_x)=5, EI(NO_x)=10, and EI(NO_x)=15. For each case, the raw emission indices were scaled to achieve these nominal EI(NO_x) values and then weight-averaged by projected fuel flow rates to yield a single set of indices for each altitude band. The resultant NO_x emission indices used for the study are shown in Table 11. Sufficient data was not available to distinguish EI(CO) and EI(HC) by altitude band.

HSCT Flight Profiles

The HSCT flight profile developed for each route depends on whether the flight path takes the aircraft over land. In the simplest case where the flight path is almost entirely over water (with the exception being a short distance from the airport to the coast as is the case from Los Angeles to Honolulu), the HSCT would take off, climb subsonically, then supersonically climb to its optimum supersonic cruise altitude. The optimum cruise altitude is a function of the aircraft gross weight and increases over the flight route as fuel is consumed. At the destination end of the route, the HSCT may supersonically descend, then subsonically descend, approach, and land.

Assumed restrictions on supersonic flight over land required either the great circle route be diverted to fly a flight path exclusively over water, as above, or the HSCT fly subsonically while over land. Depending on the number and ordering of the over land flight segments, the HSCT could execute a series of climbs and descents to reach cruise altitudes. Because of the high fuel

Table 11. Mach 1.6 HSCT Engine Exhaust Emission Indices

Altitude Band (km)	Nominal $EI(NO_X)$[a],[b] $EI(NO_X)=5$ (g/kg)	$EI(NO_X)=10$ (g/kg)	$EI(NO_X)=15$ (g/kg)	EI(CO) (g/kg)	EI(HC) (g/kg)
0-1	3.4	6.9	10.3	2.9	0.3
1-2	3.4	6.7	10.1	2.9	0.3
2-3	3.4	6.9	10.3	2.9	0.3
3-4	3.4	6.7	10.1	2.9	0.3
4-6	4.0	8.0	12.0	2.9	0.3
6-8	3.4	6.7	10.1	2.9	0.3
8-10	3.4	6.9	10.3	2.9	0.3
10-11	3.7	7.4	11.1	2.9	0.3
11-15	3.8	7.6	11.4	2.9	0.3
15-30	5.0	10.0	15.0	2.9	0.3

[a] Nominal $EI(NO_X)$ are for cruise at supersonic altitude conditions.
[b] NO_X emission index in g of NO_X as NO_2 emitted per kg of fuel.

consumption rate during supersonic climb, the flight paths MDC developed for the HSCT network contain at most one subsonic over land segment between the initial and final supersonic flight segments. In most cases, however, route diversion was able to avoid the situation where a route contained an intermediate over land segment. Corridors allowing supersonic flight over land were not considered in creating the flight paths.

Fuel Burn and Exhaust Emission Estimates

Table 12 presents the Mach 1.6 HSCT scheduled air traffic component fuel burn and engine exhaust emission estimates for the year 2015 scenario. The NO_X emission levels and effective $EI(NO_X)$ are for the case where the nominal $EI(NO_X)=5$ during supersonic cruise flight conditions. The emission estimates and effective $EI(NO_X)$ for the cases where the nominal $EI(NO_X)=10$ and $EI(NO_X)=15$ at supersonic cruise can be derived by scaling-up the shown values by a factor of two or three, respectively.

Fuel burn and engine exhaust emission levels are concentrated between 14 km and 18 km altitude corresponding to the altitude bands where supersonic cruise occurs. Secondary and tertiary peaks, roughly one order of magnitude less than the peak value, occur in the 10-11 km altitude band and 12-13 km altitude band, respectively.

Table 12. 2015 Scenario HSCT Scheduled Air Traffic Component Fuel Burn and Engine Exhaust Emission Estimates

Altitude Band (km)	Fuel (kg × 10^9)	Cumulative Fuel	NO_x [a] (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	1.07	1.1%	3.64	0.8%	3.11	1.1%	0.32	1.1%	3.40	2.90	0.30
1-2	1.08	2.2%	3.66	1.6%	3.12	2.2%	0.32	2.2%	3.40	2.90	0.30
2-3	1.08	3.2%	3.66	2.4%	3.12	3.2%	0.32	3.2%	3.40	2.90	0.30
3-4	1.08	4.3%	3.66	3.2%	3.12	4.3%	0.32	4.3%	3.40	2.90	0.30
4-5	1.08	5.4%	4.30	4.1%	3.12	5.4%	0.32	5.4%	4.00	2.90	0.30
5-6	1.08	6.5%	4.30	5.1%	3.12	6.5%	0.32	6.5%	4.00	2.90	0.30
6-7	1.08	7.6%	3.66	5.9%	3.12	7.6%	0.32	7.6%	3.40	2.90	0.30
7-8	1.08	8.7%	3.66	6.7%	3.12	8.7%	0.32	8.7%	3.40	2.90	0.30
8-9	1.08	9.7%	3.66	7.5%	3.12	9.7%	0.32	9.7%	3.40	2.90	0.30
9-10	1.50	11.2%	5.11	8.6%	4.36	11.2%	0.45	11.2%	3.40	2.90	0.30
10-11	2.54	13.8%	9.38	10.7%	7.35	13.8%	0.76	13.8%	3.70	2.90	0.30
11-12	2.08	15.9%	7.90	12.4%	6.03	15.9%	0.62	15.9%	3.80	2.90	0.30
12-13	3.32	19.2%	12.60	15.1%	9.61	19.2%	0.99	19.2%	3.80	2.90	0.30
13-14	2.50	21.7%	9.52	17.2%	7.26	21.7%	0.75	21.7%	3.80	2.90	0.30
14-15	8.86	30.6%	33.65	24.6%	25.68	30.6%	2.66	30.6%	3.80	2.90	0.30
15-16	21.33	52.1%	106.65	47.9%	61.85	52.1%	6.40	52.1%	5.00	2.90	0.30
16-17	26.66	78.9%	133.30	77.1%	77.31	78.9%	8.00	78.9%	5.00	2.90	0.30
17-18	19.50	98.5%	97.50	98.4%	56.55	98.5%	5.85	98.5%	5.00	2.90	0.30
18-19	1.48	100.0%	7.38	100.0%	4.28	100.0%	0.44	100.0%	5.00	2.90	0.30
Global Total	99.43		457.18		288.37		29.83		4.60	2.90	0.30

[a] NO_x emission estimates and effective EI(NO_x) shown are for the case where the nominal EI(NO_x)=5 at supersonic cruise flight conditions. Emission levels and effective EI(NO_x) for nominal EI(NO_x)=10 and EI(NO_x)=15 can be derived by scaling-up the data by factors of 2 or 3, respectively.

SUMMARY

MDC modeled global aircraft operations to estimate fuel burn and engine exhaust emission levels for the military, charter, and unreported domestic traffic components for a 1990 scenario. Subsequently, year 2015 scenario estimates were developed based on projected military aircraft inventory changes and commercial traffic growth. The year 2015 scenario also includes a database of fuel burn and engine exhaust emissions levels estimates for a Mach 1.6 HSCT aircraft operating on a commercial scheduled air traffic network. These databases, together with databases developed by BCAG, will contribute to assessing the environmental impact of introducing a fleet of HSCT aircraft into global commercial airline operations. The HSCT would operate at relatively high altitudes in the stratosphere where, in particular, the sensitivity of ozone concentrations to engine exhaust emission levels is not fully understood.

Aggregate Fuel Burn and Engine Exhaust Emission Estimates

Baughcum, et al. (1993b, Reference 6) analyzed the combined MDC and BCAG fuel burn and engine exhaust emission databases from all air traffic components for the 1990 and 2015 scenarios. The aggregate estimates forecast an increase in fuel burn between 1990 and 2015 of 170 billion kg (127%), from 134 billion kg to 304 billion kg, assuming no HSCT fleet exists. An HSCT fleet operating at Mach 1.6 in 2015 increases the forecast annual total fuel consumption by 65 billion kg (21%) to 369 billion kg, and 13% of the total fuel consumed is forecast to be burned above 16 km altitude.

Using the fuel burns described above, the global total NO_x emission levels increase by 1.24 billion kg (85%) from 1990 to 2015, assuming no HSCT fleet exists. Year 2015 HSCT operations at Mach 1.6, assuming $EI(NO_x)=5$, increase NO_x emission levels by 60 million kg (2%); 9% of the total NO_x emissions occur above 16 km altitude.

If instead a combustor $EI(NO_x)=15$ is assumed, year 2015 HSCT operations at Mach 1.6 increase NO_x emission levels by 970 million kg (36%); however, in this instance, 19% of the global total NO_x emissions occur above 16 km altitude.

Comparison of 1990 Estimated Jet Fuel Consumption and Reported Fuel Consumption

As a means of assessing the gross accuracy of the estimates, the fuel burn estimates developed for the 1990 scenario were compared to aggregate fuel consumption data reported by the US Department of Energy and the International Civil Aviation Organization (ICAO). No data was available to assess the accuracy of the aggregate engine exhaust emission estimates nor their geographic distribution.

The US Department of Energy reports apparent 1990 world jet fuel consumption (both naphtha-type and kerosene-type) at 3.776 million barrels per day, constituting approximately 6% of the world consumption of refined petroleum products (EIA, 1992, Reference 15). During 1990, kerosene-type jet fuel products supplied by US producers averaged 88% of the total jet fuel supplied (EIA, 1993, Reference 16). This 1990 world daily consumption is equivalent to an annual total of 173 billion kg assuming: (1) the remaining jet fuel production (12%) is naphtha-type (2) the 1990 US production experience was representative of global jet fuel production characteristics during 1990, and (3) a 7.97 barrels/metric ton conversion factor.

ICAO estimates 1990 world civil aviation industry jet fuel consumption at 136.5 billion kg of which 3.5 billion kg was used in general aviation and the remaining 133 billion kg was consumed by the commercial airlines including scheduled airlines, cargo, and turboprop operators (Balashov and Smith, 1992, Reference 3). The difference between the annual world consumption and the civil aviation industry consumption, 36.5 billion kg, is assumed to be military (non-civil) usage although other government agencies also use jet fuel. For example, in the US, the Department of Transportation, NASA, Department of Energy, and the Departments of Agriculture consumed jet fuel in 1990 albeit their consumption was a small fraction of the Department of Defense consumption (EIA, 1990, Reference 14).

MDC estimated the military aircraft operations component consumed 26 billion kg of jet fuel in the 1990 scenario, thereby accounting for approximately 71% of the purported military jet fuel usage.

Employing a bottoms-up approach, MDC and BCAG together estimated that the scheduled airline, cargo, charter, and turboprop operators consumed 108 billion kg of jet fuel in the 1990 scenario, including the unreported domestic scheduled air traffic operators in the CIS, China, and Eastern Europe (Baughcum, et al., 1993b, Reference 6). This estimate is 81% of the figure reported by ICAO.

This is the first time high resolution, three-dimensional fuel burn and engine exhaust emissions databases have been produced for such a broad scope of aircraft operations as investigated by MDC and BCAG. The accuracy of the estimates, while difficult to ascertain either on a geographic basis or in the aggregate, suggest refinements to the estimation process and/or better underlying data could prove worthwhile. However, to help guide the direction or nature of process or database enhancements, the sensitivity of the atmospheric impact assessment models to changes in the emissions databases needs to be examined.

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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 1990 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	7080	1851	630	1000	852	11,413
CIS Navy	189	402	355		380	1326
CIS Subtotal	7269	2253	985	1000	1232	12,739
US						
US Air Force	3330	1828	372	1473	1043	8046
US Navy	1523	189		1129	762	3603
US Subtotal	4853	2017	372	2602	1805	11,649
Asia/Australasia						
India	804	219	10	296	51	1380
Japan	262	88		269	191	810
Taiwan	519	98		130	40	787
North Korea	560	30	80	76		746
Pakistan	421	25		99	18	563
South Korea	343	37		133	35	548
Vietnam	382	118			14	514
Afghanistan	334	67		62		463
Thailand	122	80		142	44	388
Australia	100	58		75	56	289
Singapore	158	16		30	8	212
Indonesia	58	87		15	27	187

Region/Alliance/Country	Fighter/ Attack	Transport[a]	Bomber	Trainer	Other	Total
			Mission			
Malaysia	50	35		54	7	146
Bangladesh	59	5		40		104
Philippines	18	39		9	12	78
Mongolia	30	21		2		53
Laos	30	9		4		43
New Zealand		15		18	9	42
Burma	16	12		9		37
Sri Lanka		14			4	18
Cambodia	15					15
Papua - New Guinea		6			3	9
Nepal		3				3
Asia/Australasia Subtotal	4281	1082	90	1463	519	7435
NATO						
France	483	214	18	430	121	1266
UK	483	139		344	170	1136
West Germany	562	158		107	110	937
Italy	251	219		120	94	684
Turkey	323	126		155	70	674
Greece	300	109		61	42	512
Spain	230	86		135	46	497
Canada	98	62		206	55	421
Netherlands	155	12		32	35	234
Belgium	126	42		31	28	227
Portugal	77	15		71	19	182
Denmark	89	6		9		104
Norway	63	10		16	9	98
Luxembourg		20				20
Iceland					1	1
NATO Subtotal	3240	1218	18	1717	800	6993

Region/Alliance/Country	Mission Fighter/ Attack	Transport[a]	Bomber	Trainer	Other	Total
China						
China Air Force	4400	153	420		290	5263
China Navy	700	60	180		14	954
China Subtotal[b]	5100	213	600	0	304	6217
Middle East/North Africa						
Iraq	507	52	20	259	8	846
Israel	526	93		128	44	791
Libya	511	71	4	161	13	760
Syria	459	27		219	6	711
Egypt	442	30	9	130	33	644
Saudi Arabia	179	108		92	15	394
Algeria	221	36		90	12	359
Iran	129	76		83	8	296
Jordan	111	13		34		158
Morocco	109	29			11	149
South Yemen	107	14	5	5		131
UAE	49	17		32	7	105
North Yemen	73	12		12		97
Oman	52	42				94
Kuwait	72	8				80
Somali Republic	58	18		2		78
Sudan	37	19		12	2	70
Tunisia	23	2		8		33
Qatar	19	3				22
Bahrain	12	2				14
Mauritania	5	4			2	11
Lebanon	5	2		3		10
Djibouti		4				4
Middle East/North Africa Subtotal	3706	682	38	1270	161	5857

Region/Alliance/Country	Fighter/ Attack	Transport[a]	Bomber	Trainer	Other	Total
	Mission					
Caribbean/Latin America						
Brazil	128	204		199	67	598
Argentina	202	102	7	79	16	406
Cuba	172	53		64		289
Peru	98	89	21	47	15	270
Mexico	103	78		10	31	222
Chile	96	43		56	14	209
Venezuela	76	52	18	30	23	199
Ecuador	58	29		24	5	116
Bolivia	30	33		35	3	101
Colombia	54	39			3	96
Honduras	33	24		18		75
Uruguay	17	18		2	10	47
Guatemala	14	20		9		43
Paraguay	9	18		6		33
El Salvador	14	12		6		32
Nicaragua	6	6		17		29
Dominican Republic	10	10				20
Panama		10			4	14
Guyana		9				9
Haiti		7				7
Suriname	5					5
Bahamas		3				3
Jamaica		3				3
Costa Rica					2	2
Belize		2				2
Trinidad		1				1
Caribbean/Latin America Subtotal	1125	865	46	602	193	2831
Warsaw Pact						

Region/Alliance/Country	Fighter/ Attack	Transport[a]	Bomber	Trainer	Other	Total
			Mission			
Poland	565	59		120	35	779
Czechoslovakia	377	54		24	41	496
Romania	295	31		70	15	411
East Germany	360	33		16		409
Bulgaria	193	14		98	35	340
Hungary	101	16			11	128
Warsaw Pact Subtotal	1891	207	0	328	137	2563
Sub-Sahara Africa						
South Africa	59	60		132	164	415
Angola	163	70		22	11	266
Ethiopia	138	21		16		175
Nigeria	93	60		2	2	157
Zambia	66	25		32		123
Zimbabwe	65	25				90
Mozambique	66	8		7		81
Zaire	14	19		17		50
Kenya	28	17				45
Mali	27	4		7		38
Congo	20	11		5		36
Tanzania	24	8		2		34
Uganda	13	6		9		28
Cameroon	16	10			2	28
Gabon	9	16			1	26
Madagascar	12	11				23
Botswana	14	6				20
Togo	15	4				19
Guinea	12	2		5		19
Ghana	6	13				19
Burkina Faso	8	7				15

Region/Alliance/Country	Fighter/ Attack	Transport[a]	Bomber	Trainer	Other	Total
	Mission					
Senegal	5	7			2	14
Côte d'Ivoire	6	5				11
Chad	2	9				11
Niger		11				11
Malawi		11				11
Benin		7				7
Rwanda		7				7
Equatorial Guinea		4				4
Central African Republic		3				3
Guinea-Bissau	3					3
Cape Verde		2				2
Seychelles		1			1	2
Burundi		1				1
Sub-Sahara Africa Subtotal	884	471	0	256	183	1794
Non-Aligned Europe						
Sweden	311	8		128	60	507
Yugoslavia	289	37		110	70	506
Switzerland	268	2		100	18	388
Finland	75	9		38	11	133
Albania	95	9		6		110
Austria	24	2		22		48
Ireland	6	2			2	10
Cyprus		1				1
Non-Aligned Europe Subtotal	1068	70	0	404	161	1703
Global Total	33,417	9078	2149	9642	5495	59,781

[a] Aerial refueling (tanker) aircraft included in this category: France, 11; UK, 29; Spain, 7; Canada, 2; Luxembourg, 20; US Air Force, 706; US Navy, 92; and CIS Air Force, 74.
[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. Year 2015 mission fuel reflects a 12%

improvement over the 1990 scenario mission fuel due to expected improvements in thrust specific fuel consumption rates as mitigated by demands for increased performance.

Generic Aircraft	Mission Distance (km)	Mission Time (hr)	Mission Fuel (kg) 1990	Mission Fuel (kg) 2015	Maximum Altitude (km)	Engine Type
B1	15,467	18.10	116,587	102,597	15.2	E11
B2	2224	2.66	7045	6200	10.4	E4B
B3AF	15,467	18.10	64,770	56,998	15.2	E11
B3N	3669	4.47	21,612	19,019	11.2	E4A
B5	3669	4.47	6754	5944	11.2	E4A
B7	2224	2.66	10,064	8856	10.4	E4B
B8	2224	2.66	3019	2657	10.4	E4B
B9	2224	2.66	12,077	10,628	10.4	E4B
F1AA	2548	3.20	4891	4304	13.7	E3
F1AB	1262	1.53	4371	3846	15.2	E2
F1AC	555	2.18	3517	3095	7.6	E1
F1AD	1854	2.33	9420	8290	12.5	E10
F1B	1262	1.53	2623	2308	15.2	E2
F2	1854	2.33	8478	7461	12.5	E10
F3AF	1854	2.33	7536	6632	12.5	E10
F3N	1297	2.31	3334	2934	12.2	E9
F4	1110	2.68	5089	4478	11.7	E8
F5	1110	2.68	3957	3482	11.7	E8
F6	1297	2.31	3704	3260	12.2	E9
F7A	1110	2.68	3957	3482	11.7	E8
F7B	1110	3.57	774	681	2.4	E15
F8	1110	2.68	3732	3284	11.7	E8
F9	1297	2.31	4816	4238	12.2	E9
F10	1297	2.31	3588	3157	12.2	E9
R1AA	2222	5.27	4057	3570	6.1	E14
R1AB	1854	2.33	9420	8290	12.5	E10
R1BA	555	2.18	5275	4642	7.6	E1

Generic Aircraft	Mission Distance (km)	Mission Time (hr)	Mission Fuel (kg) 1990	2015	Maximum Altitude (km)	Engine Type
R1BB	4321	8.67	16,057	14,130	7.6	E13
R2A	1854	2.33	9420	8290	12.5	E10
R2B	2222	5.27	5164	4544	6.1	E14
R3AF	1854	2.33	11,304	9948	12.5	E10
R3AN	3669	4.47	13,507	11,886	11.2	E4A
R3BN	3674	7.63	21,002	18,482	11.4	E12A
R4	1110	2.68	3393	2986	11.7	E8
R5	1297	2.31	1852	1630	12.2	E9
R6	1110	2.68	2375	2090	11.7	E8
R7A	1110	2.68	2036	1792	11.7	E8
R7B	1110	3.57	1549	1363	2.4	E15
R8A	1110	3.57	1549	1363	2.4	E15
R8B	4321	8.67	14,273	12,560	7.6	E13
R9	1854	2.33	8478	7461	12.5	E10
R10	1110	2.68	1696	1492	11.7	E8
T1AA	3835	7.63	14,001	12,321	11.4	E12A
T1AB	14,815	19.44	107,410	94,521	12.5	E6A
T1BA	2222	5.27	4426	3895	6.1	E14
T1BB	3706	5.63	13,644	12,007	9.1	E7
T2A	1864	3.80	4743	4174	10.7	E12B
T2B	1110	3.57	1239	1090	2.4	E15
T3AFA	3835	7.63	15,401	13,553	11.4	E12A
T3AFB	14,815	19.44	96,669	85,069	12.5	E6A
T3AN	3835	7.63	15,401	13,553	11.4	E12A
T3BN	3669	4.47	13,507	11,886	11.2	E4A
T4	2222	5.27	5902	5194	6.1	E14
T5A	2222	5.27	3320	2922	6.1	E14
T5B	3835	7.63	15,401	13,553	11.4	E12A
T6	1864	3.80	5420	4770	10.7	E12B
T7	2222	5.27	3689	3246	6.1	E14

Generic Aircraft	Mission Distance (km)	Mission Time (hr)	Mission Fuel (kg) 1990	Mission Fuel (kg) 2015	Maximum Altitude (km)	Engine Type
T8A	1110	3.57	4646	4088	2.4	E15
T8B	1864	3.80	6776	5963	10.7	E12B
T9A	2222	5.27	6640	5843	6.1	E14
T9B	3705	4.81	45,279	39,846	12.5	E6B
T10A	2222	5.27	8853	7791	6.1	E14
T10B	1110	3.57	1549	1363	2.4	E15
TK1A	7268	9.75	39,217	34,511	11.9	E5
TK1BA	555	2.18	8440	7427	7.6	E1
TK1BB	3835	7.63	14,001	12,321	11.4	E12A
TK3AF	7268	9.75	31,374	27,609	11.9	E5
TR1A	1110	2.68	1018	896	11.7	E8
TR1BA	1110	2.68	3054	2688	11.7	E8
TR1BB	1110	3.57	464	408	2.4	E15
TR2	1110	2.68	1018	896	11.7	E8
TR3AF	1110	2.68	1357	1194	11.7	E8
TR4	1297	2.31	3704	3260	12.2	E9
TR6	1110	2.68	1018	896	11.7	E8
TR7A	1110	2.68	1018	896	11.7	E8
TR7B	1110	3.57	774	681	2.4	E15
TR8	1110	2.68	1357	1194	11.7	E8
TR9A	1110	2.68	1018	896	11.7	E8
TR9B	1110	3.57	464	408	2.4	E15
TR10	1110	2.68	1018	896	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.

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

Engine	Altitude Band Upper Limit (km)	Emission Indices[a] (g/kg) NOx[b]	CO	HC	Engine	Altitude Band Upper Limit (km)	Emission Indices[a] (g/kg) NOx[b]	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] These emission indices were used for both the 1990 and 2015 scenarios.
[b] 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/Alliance/ Country-Deployment	Latitude	Longitude	Region/Alliance/ Country-Deployment	Latitude	Longitude
Region I (AF)	64°39′N	147°5′W	Qatar	25°15′N	51°33′E
Region II (AF)	36°14′N	115°2′W	Saudi Arabia	24°42′N	46°43′E
Region II (AF)	21°19′N	157°55′W	Somali Republic	6°46′N	47°27′E
Region III (AF)	32°46′N	97°26′W	South Yemen	15°57′N	48°47′E
Region IV (AF)	39°49′N	84°2′W	Sudan	13°9′N	30°14′E
Region V (AF)	32°38′N	83°35′W	Syria	34°33′N	38°19′E
US-Netherlands	52°11′N	5°8′E	Tunisia	34°25′N	8°49′E
US-West Germany	50°1′N	8°34′E	UAE	23°1′N	53°55′E
US-UK	52°52′N	1°34′W	**Caribbean/Latin America**		
US-Portugal	40°9′N	8°28′W	Argentina	33°16′S	66°21′W
US-Iceland	63°59′N	22°36′W	Bahamas	25°2′N	77°28′W
US-Italy	43°5′N	12°30′E	Belize	17°32′N	88°18′W
US-Japan	36°38′N	137°11′E	Bolivia	17°0′S	65°0′W
US-South Korea	37°1′N	127°52′E	Brazil	13°17′S	50°10′W
US-Philippines	13°35′N	123°16′E	Chile	33°30′S	70°55′W
China[e]			Columbia	4°14′N	74°38′W
Lanzhou MR	36°4′N	103°52′E	Costa Rica	8°47′N	83°16′W
Beijing MR	39°56′N	116°20′E	Cuba	21°23′N	77°50′W
Shenyang MR	41°50′N	123°25′E	Dominican Republic	19°12′N	70°30′W
Jinan MR	36°41′N	116°58′E	Ecuador	1°12′S	78°34′W
Nanjing MR	32°4′N	118°47′E	El Salvador	13°26′N	89°3′W
Fuzhou MR	25°59′N	119°11′E	Guatemala	15°28′N	90°24′W
Guangzhou MR	23°2′N	113°8′E	Guyana	4°1′N	58°36′W
Wuhan MR	30°31′N	114°19′E	Hati	19°8′N	72°0′W
Kunming MR	25°8′N	102°35′E	Honduras	14°44′N	86°40′W
Chengdu MR	30°40′N	104°5′E	Jamaica	17°56′N	76°47′W
North Sea Fleet	36°10′N	120°30′E	Mexico	22°15′N	100°55′W
East Sea Fleet	31°14′N	121°30′E	Nicaragua	11°58′N	85°59′W
South Sea Fleet	21°10′N	110°15′E	Panama	9°4′N	79°22′W
Asia/Australasia			Paraguay	22°35′S	56°49′W

Region/Alliance/ Country-Deployment	Latitude	Longitude	Region/Alliance/ Country-Deployment	Latitude	Longitude
Afghanistan	34°48′N	67°49′E	Peru	8°28′S	76°27′W
Australia	23°55′S	132°48′E	Suriname	4°0′N	55°29′W
Bangladesh	23°46′N	90°23′E	Trinidad	10°35′N	61°20′W
Burma	22°35′N	95°43′E	Uruguay	32°18′S	55°46′W
Cambodia	12°14′N	104°39′E	Venezuela	7°37′N	66°10′W
India	21°5′N	79°2′E	**Warsaw Pact**		
Indonesia	0°7′N	117°28′E	Bulgaria	42°50′N	25°0′E
Japan	36°38′N	137°11′E	Czechoslovakia	49°0′N	16°40′E
Laos	18°55′N	102°27′E	East Germany	52°28′N	13°24′E
Malaysia	3°28′N	102°22′E	Hungary	47°1′N	19°48′E
Mongolia	46°20′N	102°40′E	Poland	51°45′N	19°30′E
Nepal	28°12′N	83°58′E	Romania	46°33′N	24°30′E
North Korea	39°50′N	127°30′E	**Sub-Sahara Africa**		
New Zealand	41°19′S	174°48′E	Angola	12°48′S	15°45′E
Pakistan	29°34′N	67°50′E	Benin	7°7′N	2°2′E
Papua-New Guinea	6°9′S	143°39′E	Botswana	19°58′S	23°25′E
Philippines	13°35′N	123°16′E	Burkina Faso	12°21′N	1°30′W
Singapore	1°23′N	103°42′E	Burundi	3°25′S	29°55′E
South Korea	37°1′N	127°52′E	Cameroon	3°50′N	11°31′E
Sri Lanka	5°59′N	80°19′E	Cape Verde	16°35′N	24°17′W
Taiwan	24°11′N	120°39′E	Chad	13°14′N	18°18′E
Thailand	13°54′N	100°36′E	Central African Republic	5°50′N	20°38′E
Vietnam	21°0′N	105°40′E	Congo	0°1′S	15°34′E
NATO			Côte d'Ivoire	7°45′N	5°4′W
Belgium	50°54′N	4°29′E	Ethiopia	9°0′N	38°43′E
UK	52°52′N	1°34′W	Equatorial Guinea	1°54′N	9°48′E
Canada	53°18′N	113°34′W	Gabon	0°6′S	11°56′E
Canada	43°40′N	79°37′W	Ghana	6°40′N	1°35′W
Canada-West Germany	50°1′N	8°34′E	Guinea	11°20′N	12°17′W
Denmark	56°6′N	9°23′E	Guinea Bissau	11°53′N	15°39′W

Region/Alliance/ Country-Deployment	Latitude	Longitude	Region/Alliance/ Country-Deployment	Latitude	Longitude
France	47°3′N	2°22′E	Kenya	0°20′N	37°35′E
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
Netherlands-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.

Generic Aircraft	Nominal Capacity	Nominal Range (km)	Performance[a] 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. Some generic aircraft assignments changed from the 1990 scenario to the 2015 scenario.

		Revenue Passenger Kilometers (× 10^9)		Generic Aircraft		Block Time (hr)		Block Fuel (kg)	
Route[a]	Great Circle Distance (km)	1990	2015	1990	2015	1990	2015	1990	2015
MAD-LHR	1246	20.15	41.52	C1	C1	1.9	1.9	4157	4157
MAD-FRA	1421	16.95	34.91	C1	C1	2.2	2.2	4645	4645
TFN-LHR	2876	15.04	30.98	C2	C2	3.8	3.8	14,682	14,682
ATH-LHR	2414	13.09	26.97	C1	C1	3.4	3.4	7467	7467
JFK-LHR	5537	9.89	20.37	C3	C3	6.9	6.9	23,384	23,384
ATH-FRA	1806	5.74	11.83	C1	C1	2.6	2.6	5725	5725
YYZ-LHR	5704	4.39	9.04	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	8.54	C1	C1	2.7	2.7	5883	5883
LHR-MCO	6962	3.81	8.19	C6	C6	8.4	8.4	78,518	78,518
LHR-NYC	5537	3.68	7.92	C6	C6	6.8	6.8	61,489	61,489
FCO-LHR	1444	3.68	7.58	C1	C1	2.2	2.2	4707	4707
LCA-LHR	3275	3.57	7.36	C2	C2	4.2	4.2	16,661	16,661
LHR-MIA	7104	3.04	6.54	C6	C6	8.5	8.5	80,270	80,270
MLA-LHR	2099	2.82	5.81	C1	C1	3.0	3.0	6560	6560
IST-LHR	2511	2.79	5.76	C1	C1	3.5	3.5	7748	7748

Route[a]	Great Circle Distance (km)	Revenue Passenger Kilometers (× 10^9)		Generic Aircraft		Block Time (hr)		Block Fuel (kg)	
		1990	2015	1990	2015	1990	2015	1990	2015
LHR-BGR	4937	2.63	5.66	C6	C6	6.1	6.1	54,636	54,636
BEG-LHR	1699	2.38	4.91	C1	C1	2.5	2.5	5423	5423
YYZ-CDG	6015	2.38	4.90	C3	C3	7.5	7.5	25,624	25,624
ATH-CDG	2097	2.22	4.58	C1	C1	3.0	3.0	6552	6552
TUN-FRA	1471	2.18	4.50	C1	C1	2.2	2.2	4782	4782
JFK-CDG	5830	2.11	4.35	C3	C3	7.3	7.3	24,750	24,750
NBO-FRA	6312	2.08	4.28	C3	C3	7.8	7.8	27,042	27,042
LHR-YYZ	5704	1.66	3.57	C4	C6	7.1	7.0	30,919	63,420
MAD-CDG	1065	1.61	3.32	C1	C1	1.7	1.7	3659	3659
LHR-DTW	6040	1.52	3.28	C6	C6	7.3	7.3	67,376	67,376
ACA-YYZ	3540	1.47	3.16	C4	C5	4.6	4.6	19,353	28,643
TUN-LHR	1830	1.45	2.99	C1	C1	2.7	2.7	5792	5792
IST-CDG	2235	1.43	2.94	C1	C1	3.2	3.2	6949	6949
MEX-LHR	8900	1.32	2.72	C3	C3	10.9	10.9	40,219	40,219
LHR-LAX	8755	1.28	2.75	C6	C6	10.4	10.4	101,507	101,507
TUN-CDG	1488	1.24	2.55	C1	C1	2.2	2.2	4831	4831
VIE-LHR	1270	1.23	2.53	C1	C1	2.0	2.0	4224	4224
BGI-LHR	6747	1.20	2.46	C3	C3	8.3	8.3	29,151	29,151
ACA-NYC	3640	1.15	2.48	C5	C5	4.7	4.7	29,428	29,428
LIS-FRA	1873	1.12	2.30	C1	C1	2.7	2.7	5915	5915
BKK-FRA	8963	1.09	2.25	C3	C3	10.9	10.9	40,560	40,560
FRA-MCO	7616	1.09	2.35	C6	C6	9.1	9.1	86,694	86,694
FRA-NYC	6186	1.08	2.32	C6	C6	7.5	7.5	69,107	69,107
DKR-CDG	4223	1.07	2.21	C2	C2	5.4	5.4	21,531	21,531
SDQ-FRA	7612	1.02	2.11	C3	C3	9.4	9.4	33,475	33,475
CAI-FRA	2918	0.98	2.02	C2	C2	3.8	3.8	14,890	14,890
CDG-YYZ	6015	0.96	2.06	C4	C6	7.5	7.3	32,633	67,077
SDQ-LHR	6979	0.91	1.87	C3	C3	8.6	8.6	30,297	30,297
LHR-CHI	6340	0.87	1.87	C6	C6	7.7	7.7	70,945	70,945
FRA-MIA	7757	0.87	1.87	C6	C6	9.3	9.3	88,497	88,497

Route[a]	Great Circle Distance (km)	Revenue Passenger Kilometers (× 10^9)		Generic Aircraft		Block Time (hr)		Block Fuel (kg)	
		1990	2015	1990	2015	1990	2015	1990	2015
TLV-LHR	3588	0.84	1.73	C2	C2	4.6	4.6	18,242	18,242
TPA-YYZ	1765	0.84	1.80	C4	C5	2.5	2.5	10,310	15,440
FCO-CDG	1102	0.83	1.71	C1	C1	1.8	1.8	3760	3760
BEG-FRA	1053	0.80	1.65	C1	C1	1.7	1.7	3626	3626
FRA-BGR	5583	0.78	1.68	C6	C6	6.8	6.8	62,017	62,017
NBO-CDG	6492	0.73	1.51	C3	C3	8.0	8.0	27,907	27,907
TLV-FRA	2953	0.72	1.48	C2	C2	3.9	3.9	15,061	15,061
CAI-CDG	3208	0.70	1.44	C2	C2	4.2	4.2	16,325	16,325
ZRH-LHR	788	0.68	1.39	C1	C1	1.4	1.4	2902	2902
TLV-CDG	3284	0.67	1.38	C2	C2	4.3	4.3	16,709	16,709
LCA-FRA	2634	0.66	1.36	C1	C1	3.7	3.7	8106	8106
SOF-LHR	2038	0.66	1.35	C1	C1	2.9	2.9	6384	6384
FRA-FLL	7728	0.65	1.40	C6	C6	9.2	9.2	88,122	88,122
ACA-YMX	4000	0.61	1.31	C4	C5	5.1	5.1	21,762	32,300
MEX-FRA	9547	0.60	1.24	C3	C3	11.6	11.6	43,746	43,746
ACA-MCO	2290	0.60	1.28	C5	C5	3.1	3.1	19,198	19,198
MIA-YYZ	1988	0.58	1.26	C4	C5	2.7	2.8	11,423	17,018
POP-YYZ	2781	0.58	1.25	C4	C5	3.7	3.7	15,437	22,821
GIG-FRA	9563	0.57	1.18	C3	C3	11.6	11.6	43,834	43,834
LHR-BOS	5236	0.57	1.22	C6	C6	6.4	6.4	58,029	58,029
LHR-YMX	5217	0.56	1.20	C4	C6	6.6	6.4	28,265	57,811
CMB-FRA	8061	0.54	1.11	C3	C3	9.9	9.9	35,784	35,784
FRA-LHR	654	0.52	1.07	C1	C1	1.2	1.2	2539	2539
KIN-LHR	7513	0.52	1.07	C3	C3	9.2	9.2	32,972	32,972
NRT-NYC	10,826	0.50	1.09	C6	C6	12.7	12.7	130,219	130,219
LHR-EWR	5560	0.50	1.08	C6	C6	6.8	6.8	61,746	61,746
NBO-LHR	6836	0.50	1.03	C3	C3	8.4	8.4	29,590	29,590
FCO-FRA	959	0.50	1.02	C1	C1	1.6	1.6	3369	3369
LHR-FRA	654	0.48	0.98	C1	C1	1.2	1.2	2539	2539
HAV-FRA	8128	0.47	0.97	C3	C3	10.0	10.0	36,135	36,135

Route[a]	Great Circle Distance (km)	Revenue Passenger Kilometers (× 10^9) 1990	2015	Generic Aircraft 1990	2015	Block Time (hr) 1990	2015	Block Fuel (kg) 1990	2015
ACA-MIA	2252	0.46	0.99	C5	C5	3.1	3.1	18,919	18,919
CAS-FRA	1301	0.45	0.93	C1	C1	2.0	2.0	4311	4311
CDG-NYC	5830	0.45	0.96	C6	C6	7.1	7.1	64,898	64,898
AMS-NYC	5845	0.45	0.96	C6	C6	7.1	7.1	65,072	65,072
CAS-CDG	854	0.44	0.91	C1	C1	1.4	1.4	3082	3082
CAI-LHR	3528	0.44	0.91	C2	C2	4.5	4.5	17,941	17,941
FRA-DTW	6674	0.44	0.95	C6	C6	8.0	8.0	74,988	74,988
CDG-LHR	346	0.44	0.91	C1	C1	0.8	0.8	1713	1713
LHR-CDG	346	0.44	0.90	C1	C1	0.8	0.8	1713	1713
MLE-FRA	7875	0.44	0.90	C3	C3	9.7	9.7	34,821	34,821
WTD-NYC	1622	0.44	0.94	C5	C5	2.4	2.4	14,442	14,442
SOF-FRA	1395	0.42	0.87	C1	C1	2.1	2.1	4571	4571
CCS-YYZ	3873	0.41	0.89	C4	C5	5.0	4.9	21,091	31,276
BKK-LHR	9540	0.41	0.85	C3	C3	11.6	11.6	43,709	43,709
ACA-DTW	3230	0.39	0.83	C5	C5	4.2	4.2	26,234	26,234
TPA-YMX	2104	0.37	0.79	C4	C5	2.9	2.9	12,007	17,852
AMS-MIA	7437	0.37	0.79	C6	C6	8.9	8.9	84,441	84,441
CDG-MIA	7365	0.36	0.78	C6	C6	8.8	8.8	83,533	83,533
LHR-YVR	7575	0.36	0.77	C4	C6	9.3	9.0	41,406	86,177
FRA-LAX	9317	0.36	0.77	C6	C6	11.0	11.0	109,064	109,064
ACA-FLL	2274	0.35	0.75	C5	C5	3.1	3.1	19,077	19,077
FRA-YYZ	6340	0.33	0.72	C4	C6	7.9	7.7	34,432	70,942
MEX-CDG	9193	0.33	0.67	C3	C3	11.2	11.2	41,809	41,809
CDG-YMX	5526	0.32	0.70	C4	C6	6.9	6.8	29,946	61,357
Total		189.02	392.91						

[a] Although the charter air traffic component network model is nondirectional, routes are defined by origin-destination city or airport pair codes (MDC, 1990, Reference 25). 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 2015 scenario.

		Available Seat Kilometers (× 10^9)				
Route[a]	**Great Circle Distance (km)**	**1990**	**2015**	**Generic Aircraft**	**Block Time (hr)**	**Block Fuel (kg)**
KWE-PEK	1729	27.04	51.54	S2	2.7	5425
CAN-YIN	3717	26.25	50.02	S3	4.8	20,879
HRB-KHG	4108	26.25	50.02	S3	5.3	23,196
IST-AZZ	1744	23.34	44.48	S3	2.5	10,069
BUD-GDN	776	15.56	29.65	S2	1.5	2818
DME-KHV	6135	8.82	16.80	S1	7.5	39,653
DME-TAS	2769	6.07	11.57	S1	3.6	18,386
ALA-DME	3080	5.91	11.26	S1	4.0	20,281
EVN-VKO	1793	5.52	10.52	S3	2.6	10,318
DME-IKT	4190	5.04	9.60	S3	5.4	23,686
DME-SVX	1410	4.92	9.37	S1	2.1	10,253
AER-VKO	1361	3.92	7.47	S1	2.0	9967
MRV-VKO	1314	3.15	6.01	S1	2.0	9692
TBS-VKO	1630	2.94	5.60	S3	2.4	9487
SUI-VKO	1412	2.86	5.44	S1	2.1	10,268
DME-HTA	4727	2.84	5.41	S3	6.0	26,976
SIP-VKO	1200	2.79	5.33	S1	1.8	9018
UUD-VKO	4438	2.67	5.08	S3	5.7	25,196
DME-FRU	2964	2.38	4.53	S3	3.9	16,578
DME-DYU	2946	2.36	4.50	S3	3.9	16,478
BAK-DME	1887	2.27	4.32	S3	2.7	10,805
DME-OVB	2810	2.25	4.29	S3	3.8	15,726
DME-NOZ	3109	1.87	3.56	S3	4.1	17,389
KEJ-VKO	3012	1.81	3.45	S3	4.0	16,843
BAX-DME	2923	1.76	3.35	S3	3.9	16,349
MMK-SVO	1459	1.75	3.34	S3	2.2	8628
KBP-LED	1068	1.68	3.21	S1	1.7	8250
KIV-VKO	1110	1.56	2.97	S3	1.8	6906

Route[a]	Great Circle Distance (km)	Available Seat Kilometers (× 10^9) 1990	2015	Generic Aircraft	Block Time (hr)	Block Fuel (kg)
DME-TJM	1883	1.51	2.88	S3	2.7	10,783
BTK-KHV	2371	1.49	2.85	S3	3.2	13,344
LED-SVO	619	1.49	2.84	S2	1.3	2407
ASB-DME	2471	1.49	2.83	S3	3.4	13,881
DME-KGF	2431	1.46	2.79	S3	3.3	13,667
KRR-VKO	1174	1.37	2.61	S3	1.8	7219
DME-OMS	2223	1.34	2.55	S3	3.1	12,559
DME-SGC	2131	1.28	2.44	S3	3.0	12,071
LED-ODS	1495	1.20	2.28	S3	2.2	8809
DME-UFA	1148	1.15	2.19	S3	1.8	7092
KBP-TBS	1428	1.14	2.18	S3	2.1	8474
ROV-VKO	932	1.12	2.14	S3	1.6	6047
ODS-VKO	1110	1.11	2.12	S3	1.8	6906
LED-MMK	1014	1.05	1.99	S3	1.7	6445
KBP-VKO	719	1.01	1.93	S3	1.3	5036
DME-VOG	865	1.01	1.93	S1	1.5	7069
RIX-SVO	826	1.00	1.91	S3	1.4	5539
MCX-VKO	1582	0.95	1.81	S3	2.3	9245
IKT-OVB	1423	0.90	1.71	S3	2.1	8450
EVN-SIP	1002	0.80	1.53	S3	1.6	6383
ODS-RIX	1246	0.78	1.50	S3	1.9	7575
LWO-VKO	1174	0.78	1.49	S1	1.8	8871
ALA-TAS	670	0.73	1.39	S1	1.2	5938
AER-KBP	1026	0.70	1.34	S3	1.7	6501
DME-PEE	1153	0.69	1.32	S3	1.8	7119
BKA-MQF	1370	0.69	1.31	S1	2.0	10,017
LWO-SIP	877	0.65	1.24	S3	1.5	5782
KBP-SIP	641	0.55	1.05	S3	1.2	4667
SVO-TLL	842	0.52	0.99	S2	1.6	2994
DOK-VKO	834	0.52	0.99	S1	1.4	6887

Route[a]	Great Circle Distance (km)	Available Seat Kilometers (× 10^9) 1990	2015	Generic Aircraft	Block Time (hr)	Block Fuel (kg)
MSQ-SVO	673	0.52	0.98	S2	1.4	2546
ASF-DME	1230	0.51	0.97	S2	2.1	4040
DME-KUF	831	0.50	0.95	S3	1.4	5565
DME-REN	1202	0.50	0.95	S2	2.0	3964
TAS-UGC	737	0.49	0.94	S3	1.3	5119
BUS-VKO	1546	0.48	0.91	S2	2.5	4913
VKO-VSG	791	0.48	0.91	S3	1.4	5377
DME-KZN	699	0.47	0.89	S1	1.3	6103
DME-ULY	681	0.42	0.80	S1	1.2	5998
KHV-UUS	586	0.40	0.77	S3	1.2	4408
ARH-SVO	971	0.40	0.76	S2	1.7	3338
SCW-SVO	970	0.40	0.76	S2	1.7	3337
SVO-UCT	1240	0.38	0.73	S2	2.1	4066
KBP-KRR	839	0.38	0.72	S1	1.4	6913
KBP-ROV	724	0.38	0.72	S3	1.3	5057
KBP-TLL	1085	0.35	0.67	S2	1.9	3646
DME-RTW	688	0.34	0.66	S1	1.3	6041
HRK-VKO	624	0.31	0.60	S2	1.3	2418
ARH-LED	745	0.31	0.59	S2	1.4	2737
LED-MSQ	693	0.29	0.54	S2	1.4	2599
MSQ-ODS	848	0.26	0.50	S2	1.6	3009
SVO-VNO	201	0.20	0.38	S1	0.7	3242
BAK-EVN	465	0.14	0.27	S2	1.1	2006
SKD-TAS	266	0.10	0.19	S3	0.8	2934
SUI-TBS	629	0.09	0.17	S3	1.2	4609
IEV-OZH	450	0.08	0.15	S3	1.0	3777
ROV-VOG	390	0.08	0.14	S3	0.9	3502
IEV-ODS	434	0.08	0.14	S3	1.0	3702
ASB-MYP	305	0.07	0.13	S3	0.8	3115
BAK-TBS	456	0.07	0.13	S3	1.0	3806

Route[a]	Great Circle Distance (km)	Available Seat Kilometers (× 10⁹) 1990	2015	Generic Aircraft	Block Time (hr)	Block Fuel (kg)
FEG-TAS	225	0.05	0.10	S3	0.7	2748
DYU-SKD	186	0.04	0.08	S3	0.7	2572
ALA-FRU	206	0.03	0.06	S3	0.7	2665
Total		235.64	449.11			

[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, Reference 25). 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.

APPENDIX C: Mach 1.6 HSCT Scheduled Air Traffic Component

This appendix provides details on the commercial scheduled air traffic network model used to estimate fuel burn and engine exhaust emissions levels due to Mach 1.6 High-speed Civil Transport operations in the year 2015.

Route[a]			Distance			
Origin	Via	Destination	Great Circle (km)	Flight Path[b] (km)	Available Seat Kilometers ($\times 10^9$)	Daily Trips
AKL	MNL	HKG	9143	9275	3.63	4
AKL		HNL	7086	7086	16.86	22
AKL	HNL	LAX	10,480	11,192	18.70	17
AKL		NRT	8830	8830	8.75	10
AKL		PPT	4091	4091	0.81	2
AKL		SIN	8410	9019	5.00	6
AMS		ATL	7060	7595	2.80	4
AMS		BOS	5543	5815	1.10	2
AMS		CCS	7834	7871	1.55	2
AMS		DFW	7893	8710	1.56	2
AMS		JFK	5843	6143	5.79	10
AMS	YYC	LAX	8949	9466	3.55	4
AMS		MSP	6680	7452	1.32	2
AMS	HEL	NRT	9312	9940	1.85	2
AMS		ORD	6606	7493	1.31	2
AMS	BAH	SIN	10,499	12,270	4.16	4
AMS		YMX	5504	6134	1.09	2
AMS		YYZ	5986	6651	2.37	4
ANC		CDG	7514	7630	1.49	2
ANC		HKG	8143	8640	1.61	2
ANC		LHR	7195	7352	1.43	2
ANC		NRT	5510	5613	8.74	15
ANC		TPE	7514	7847	2.98	4
ATH		JFK	7915	8293	1.57	2
ATH	BAH	SIN	9047	9801	1.79	2

Route[a]			Distance			
Origin	Via	Destination	Great Circle (km)	Flight Path[b] (km)	Available Seat Kilometers ($\times 10^9$)	Daily Trips
ATL		CDG	7049	7425	1.40	2
ATL		FRA	7402	7834	7.34	10
ATL		GVA	7417	7738	1.47	2
ATL		LGW	6756	7254	6.70	10
BAH		BOM	2411	2411	1.43	6
BAH		CGK	7039	7191	12.56	17
BAH		FRA	4436	4952	2.64	6
BAH		GVA	4486	4860	0.89	2
BAH		MNL	7364	9427	1.46	2
BAH		SIN	6319	6862	17.54	26
BKK		CAI	7251	8315	2.87	4
BKK	BAH	CPH	8601	12,079	5.12	6
BKK		DHA	5404	6482	3.21	6
BOG		JFK	3993	3993	1.41	4
BOM		CDG	6989	7793	1.39	2
BOM		GVA	6710	7447	1.33	2
BOM		NBO	4530	4530	0.90	2
BOS		CDG	5528	5595	1.10	2
BOS		FRA	5884	6019	2.33	4
BOS		GVA	5899	6010	1.17	2
BOS		LHR	5236	5423	6.23	11
BOS		SNN	4641	4719	1.84	4
BRU		JFK	5882	6073	4.66	8
BRU	HEL	NRT	9451	10,216	1.87	2
BRU		ORD	6671	7234	1.32	2
BRU		YMX	5556	6052	1.10	2
BUD		JFK	7010	7332	1.39	2
CCS		FCO	8328	8510	1.65	2
CCS		LIS	6497	6497	1.29	2

Route[a]			Distance			
Origin	Via	Destination	Great Circle (km)	Flight Path[b] (km)	Available Seat Kilometers (× 10^9)	Daily Trips
CCS		MAD	6999	6999	2.78	4
CDG		GIG	9179	9460	3.64	4
CDG		IAD	6191	6256	3.68	6
CDG	HEL	NRT	9703	10,466	9.62	10
CDG	BAH	SIN	10,710	12,071	2.12	2
CDG		SJU	6915	6915	10.97	15
CDG		YMX	5526	5919	6.57	11
CDG		YYZ	6015	6404	1.19	2
CGK		NRT	5825	5921	5.77	10
CPH		JFK	6184	6793	1.23	2
CPH		LAX	9021	9566	1.79	2
CPH	HEL	NRT	8704	9391	1.73	2
CPH		SEA	7804	8499	1.55	2
DFW		FRA	8251	8901	3.27	4
DFW		LGW	7621	8284	9.07	11
DFW	SEA	NRT	10,314	10,334	6.13	6
DFW		ORY	7938	8467	3.15	4
DHA		BOM	2458	2458	0.97	4
DHA		CDG	4786	5173	0.95	2
DHA		LHR	5058	5487	3.01	6
DHA		MNL	7410	9462	10.28	13
DHA		SIN	6363	6895	6.31	10
DKR		CDG	4223	4449	5.02	11
DTW		CDG	6352	6601	2.52	4
DTW		FRA	6673	7025	2.65	4
DTW		LHR	6039	6428	1.20	2
DTW	SEA	NRT	10,264	10,762	10.17	10
DTW	SEA	SEL	10,627	11,545	10.53	10
EZE	TFN	MAD	10,077	10,469	4.00	4

Route[a]			Distance			
Origin	Via	Destination	Great Circle (km)	Flight Path[b] (km)	Available Seat Kilometers ($\times 10^9$)	Daily Trips
FCO	HEL	NRT	9895	11,186	1.96	2
FCO		YYZ	7080	7421	1.40	2
FRA	TFN	GIG	9562	9949	3.79	4
FRA		IAD	6545	6704	3.89	6
FRA		JFK	6186	6352	15.94	24
FRA	YYC	LAX	9314	9825	5.54	6
FRA		MIA	7756	7810	6.15	8
FRA	HEL	NRT	9360	10,236	9.28	10
FRA		SFO	9141	9638	1.81	2
FRA	BAH	SIN	10,266	11,814	6.11	6
FRA		YMX	5854	6367	1.16	2
FRA		YYC	7523	8119	1.49	2
FRA		YYZ	6338	6852	3.77	6
GIG		FCO	9166	9743	3.63	4
GUM		HNL	6104	6104	6.05	10
GUM		SIN	4691	4880	0.93	2
GUM		SYD	5313	5669	1.05	2
GVA		JFK	6197	6251	4.91	8
GVA		YMX	5910	6347	1.17	2
HEL		JFK	6602	6938	1.31	2
HKG	NRT	LAX	11,634	12,005	16.15	13
HKG	NRT	SEA	10,418	10,931	6.20	6
HKG	NRT	SFO	11,101	11,479	24.21	20
HKG		SYD	7373	8328	16.08	20
HKG	NRT	YVR	10,247	10,793	16.25	15
HNL		LAX	4104	4104	25.22	57
HNL		MNL	8514	8514	8.44	10
HNL		NRT	6132	6132	65.65	99
HNL		OSA	6588	6588	18.28	26

Route[a]			Distance			
Origin	Via	Destination	Great Circle (km)	Flight Path[b] (km)	Available Seat Kilometers ($\times 10^9$)	Daily Trips
HNL		PHX	4682	4682	0.93	2
HNL		PPT	4413	4413	6.12	13
HNL		SEA	4304	4304	3.41	8
HNL		SEL	7315	8577	10.15	13
HNL		SFO	3852	3852	13.75	33
HNL		SYD	8165	8177	29.14	33
HNL		TPE	8138	8138	6.45	8
HNL		YVR	4347	4347	4.31	10
JFK		ARN	6288	6556	1.25	2
JFK		CDG	5830	5904	13.87	22
JFK		FBU	5912	6150	1.17	2
JFK		FCO	6860	7158	13.60	19
JFK	SEA	NRT	10,823	11,555	45.06	39
JFK	SEA	SEL	11,064	12,338	10.97	10
JFK		SNN	4943	5030	1.96	4
JFK	FCO	TLV	9112	9604	3.61	4
JFK		WAW	6843	7069	1.36	2
JNB		GIG	7147	7147	1.42	2
LAX	YYC	CDG	9093	9419	3.61	4
LAX	JFK	FCO	10,193	11,129	2.02	2
LAX	UIO	GIG	10,130	10,405	2.01	2
LAX		LHR	8753	9266	12.15	13
LAX	HNL	MEL	12,749	13,070	10.11	8
LAX		NRT	8747	8747	60.69	64
LAX		OSA	9177	9177	5.46	6
LAX	NRT	PEK	10,029	11,306	1.99	2
LAX		PPT	6606	6606	3.93	6
LAX	HNL	SYD	12,053	12,281	16.73	13
LAX	NRT	TPE	10,914	10,914	17.31	15

Route[a]			Distance			
Origin	Via	Destination	Great Circle (km)	Flight Path[b] (km)	Available Seat Kilometers ($\times 10^9$)	Daily Trips
LGW		SJU	6728	6728	5.34	8
LGW		STL	6738	7934	1.34	2
LHR		GIG	9247	9501	3.67	4
LHR		IAD	5897	6038	7.01	11
LHR		JFK	5537	5686	29.64	50
LHR		MIA	7102	7115	9.86	13
LHR		MSP	6438	7212	1.28	2
LHR	HEL	NRT	9584	10,440	20.90	20
LHR		SEA	7697	8140	1.53	2
LHR		SFO	8610	9029	5.12	6
LHR	BAH	SIN	10,868	12,386	17.24	15
LHR		YMX	5217	5749	2.07	4
LHR		YVR	7575	8017	1.50	2
LHR		YYC	7012	7608	1.39	2
LHR		YYZ	5702	6141	7.91	13
LIM		MIA	4215	4993	2.51	6
LIS		GIG	7710	8091	3.06	4
LIS		JFK	5400	5400	2.14	4
MAD		GIG	8140	8506	4.84	6
MAD		JFK	5758	5758	5.71	10
MAD		MEX	9060	9508	3.59	4
MAD		MIA	7101	7101	2.82	4
MAD		SJU	6378	6378	2.53	4
MIA		CDG	7364	7364	2.92	4
MIA		SCL	6652	7349	2.64	4
MNL		SYD	6260	7952	3.72	6
MRU		SIN	5580	6136	1.11	2
MRU		TPE	8523	9375	1.69	2
MSP	SEA	NRT	9545	9914	3.78	4

	Route[a]		Distance			
Origin	Via	Destination	Great Circle (km)	Flight Path[b] (km)	Available Seat Kilometers (× 10^9)	Daily Trips
NRT	SEA	IAD	10,836	11,371	12.89	11
NRT		YVR	7501	7536	13.38	17
NRT	YVR	YYZ	10,292	10,879	4.08	4
ORD		CDG	6658	7078	2.64	4
ORD		FCO	7734	8091	3.07	4
ORD		FRA	6965	7514	8.29	11
ORD		GVA	7049	7419	2.79	4
ORD		LHR	6339	6802	7.54	11
ORD	SEA	NRT	10,066	10,430	25.94	24
OSA		SIN	4941	4941	6.86	13
PDX		NRT	7736	7736	4.60	6
PDX		SEL	8456	8530	5.03	6
PER		NRT	7940	8556	4.72	6
PPT		NRT	9438	9438	3.74	4
PPT		SFO	6758	6758	1.34	2
PPT		SYD	6113	6113	1.21	2
SEA		NRT	7651	7673	13.65	17
SEA		SEL	8340	8456	1.65	2
SEA	NRT	TPE	9749	9825	1.93	2
SEL		SIN	4650	4699	0.92	2
SEL		YVR	8169	8365	3.24	4
SFO		NRT	8221	8221	47.27	53
SFO	HNL	SYD	11,942	12,031	4.73	4
SFO	NRT	TPE	10,384	10,384	10.29	10
SIN		NRT	5358	5358	33.99	59
SIN		TLV	7951	8493	1.58	2
SIN		TPE	3222	3222	1.28	4
SIN	BAH	VIE	9690	11,666	1.92	2
SVO		JFK	7477	7775	2.96	4

Route[a]			Distance			
Origin	Via	Destination	Great Circle (km)	Flight Path[b] (km)	Available Seat Kilometers ($\times 10^9$)	Daily Trips
SYD		NRT	7827	8125	31.03	37
TPE	NRT	YVR	9586	9688	1.90	2
		Total			1336.99	1747

[a] Although the traffic is nondirectional, routes are defined by origin-destination city or airport pair codes (MDC, 1990, Reference 25), and the origin-destination distinction is a matter of convenience. 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 is on city code for multiple airports.
[b] Includes any extra distance due to route diversion.

Cities associated with airport/city codes identified in this document are shown below:

CODE	CITY SERVED	CODE	CITY SERVED	CODE	CITY SERVED	CODE	CITY SERVED
ACA	ACAPULCO	EWR	NEWARK	MAD	MADRID	SEL	SEOUL
AER	ADDLER USSR	EZE	BUENOS AIRES	MCO	ORLANDO	SFO	SAN FRANCISCO
AKL	AUCKLAND	FBU	OSLO	MEL	MELBOURNE	SIN	SINGAPORE
ALA	ALMA ATA USSR	FCO	ROME	MEX	MEXICO CITY	SIP	SIMFEROPOL USSR
AMS	AMSTERDAM	FEG	FERGANA USSR	MIA	MIAMI	SJU	SAN JUAN
ANC	ANCHORAGE	FLL	FT. LAUDERDALE	MLA	MALTA	SKD	SAMARKAND USSR
ARH	ARKHANGEL USSR	FRA	FRANKFURT	MLE	MALDIVES	SNN	SHANNON
ARN	STOCKHOLM	FRU	FRUNZE USSR	MMK	MURMANSK	SOF	SOFIA
ASB	ASHKHABAD USSR	GDN	GDANSK	MNL	MANILA	STL	ST. LOUIS
ASF	ASTRAKHAN USSR	GIG	RIO DE JANEIRO	MOW	MOSCOW	STO	STOCKHOLM
ATH	ATHENS	GUM	GUAM	MRU	MAURITIUS	SUI	SUKHUMI USSR
ATL	ATLANTA	GVA	GENEVA	MRV	MINERAL USSR	SVO	MOSCOW
AZZ	AMBRIZ	HAV	HAVANA	MSP	MINNEAPOLIS	SVX	SVERDLOVSK USSR
BAH	BAHRAIN	HEL	HELSINKI	MSQ	MINSK	SYD	SYDNEY
BAK	BAKU USSR	HKG	HONG KONG	MYP	MARY USSR	TAS	TASKENT USSR
BAX	BARNAUL USSR	HNL	HONOLULU	NBO	NAIROBI	TBS	TBILISI USSR
BEG	BELGRADE	HRB	HARBIN PRC	NOZ	NOVOKUZNETSK	TFN	TENERIFE
BGI	BARBADOS	HRK	KHARKOV USSR	NRT	TOKYO	TLL	TALLINN USSR
BGR	BANGOR	HTA	CHITA USSR	NYC	NEW YORK	TLV	TEL AVIV
BKK	BANGKOK	IAD	WASHINGTON	ODS	ODESSA USSR	TPA	TAMPA
BOG	BOGOTA	IEV	KIEV USSR	ORD	CHICAGO	TPE	TAIPEI
BOM	BOMBAY	IKT	IRKUSTK USSR	ORY	PARIS	TUN	TUNIS
BOS	BOSTON	IST	ISTANBUL	OSA	OSAKA	UCT	UKHTA USSR
BRU	BRUSSELS	JFK	NEW YORK	OSL	OSLO	UGC	URGENCH USSR
BUD	BUDAPEST	JKT	JAKARTA	OVB	NOVOSIBIRSK	UIO	QUITO
BUE	BUENOS AIRES	JNB	JOHANNESBURG	OZH	ZAPOROZHYE USSR	ULY	ULYANOVSK USSR
BUS	BATUMI USSR	KBP	KIEV USSR	PAR	PARIS	UUD	ULANUDE USSR
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CAS	CASABLANCA	KHV	KHABAROVSK USSR	PEK	PEKING	VKO	MOSCOW
CCS	CARACAS	KIN	KINGSTON	PER	PERTH	VNO	VILNIUS USSR
CDG	PARIS	KIV	KISHINEV USSR	PHX	PHOENIX	VOG	VOLGOGRAD USSR
CGK	JAKARTA	KRR	KRASNODAR USSR	POP	PUERTO PLATA	VSG	LUGANSK USSR
CHI	CHICAGO	KUF	KUJBYSEV USSR	PPT	TAHITI	WAS	WASHINGTON
CMB	COLOMBO	KWE	GUIYANG PRC	REN	ORENBURG USSR	WAW	WARSAW
CPH	COPENHAGEN	KZN	KAZAM USSR	RIO	RIO DE JANEIRO	WTD	BAHAMAS
DFW	DALLAS	LAX	LOS ANGELES	ROM	ROME	YIN	YINING PRC
DHA	DAHRAIN	LCA	LARNACA	ROV	ROSTOV USSR	YMQ	MONTREAL
DKR	DAKAR	LED	LENINGRAD	RTW	SARATOV	YMX	MONTREAL
DME	MOSCOW	LGW	LONDON	SCL	SANTIAGO	YVR	VANCOUVER
DTW	DETROIT	LHR	LONDON	SCW	SYKTYVKAR USSR	YYC	CALGARY
DYU	DUSHANBE USSR	LIM	LIMA	SDQ	SANTO DOMINGO	YYZ	TORONTO
EVN	EREVAN USSR	LIS	LISBON	SEA	SEATTLE	ZRH	ZURICH

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 1994

3. REPORT TYPE AND DATES COVERED
Contractor Report

4. TITLE AND SUBTITLE
Jet Aircraft Engine Exhaust Emissions Database Development—
Year 1990 and 2015 Scenarios

5. FUNDING NUMBERS
C NAS1-19345
WU 537-01-22-01

6. AUTHOR(S)
Z. H. Landau, M. Metwally, R. Van Alstyne, and C. A. Ward

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
McDonnell Douglas Aerospace
Transport Aircraft
3855 Lakewood Boulevard
Long Beach, CA 90846

8. PERFORMING ORGANIZATION REPORT NUMBER
CRAD-9103-TR-9248

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA CR-4613

11. SUPPLEMENTARY NOTES
Langley Technical Monitor: Donald L. Maiden
McDonnell Douglas Technical Monitor: Munir Metwally

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 45

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Studies relating to environmental emissions associated with High Speed Civil Transport (HSCT) military jet and charter jet aircraft were conducted by McDonnell Douglas Aerospace Transport Aircraft. The report includes jet engine emission results for baseline 1990 charter and military scenario. The projected jet engine emissions results for a 2015 scenario for a Mach 1.6 HSCT fleet, and a charter and military fleet. Discussions of the methodology used in formulating these databases are provided.

14. SUBJECT TERMS
High Speed Civil Transport (HSCT); Stratospheric emissions; Jet fleet scenarios

15. NUMBER OF PAGES
88

16. PRICE CODE
A05

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	