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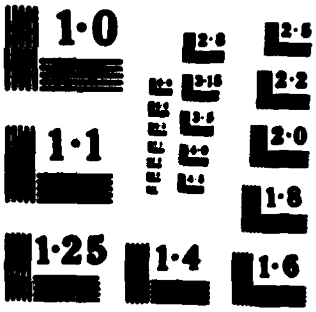
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16. Abstract

The first part of this report addresses the status of the AVAP model and AQAM from the perspective of the modeling requirements of users concerned with air-quality problems in civilian and military aviation. Brief descriptions of the types of problems likely to be encountered is followed by a detailed discussion of those characteristics of the problems that determine the technical requirements for the applicable computational procedures or models. This is followed by a discussion of the operational or user requirements of the models. Then a review and evaluation of the AVAP model and AQAM is given that includes a discussion of their intended uses, strengths, and weaknesses. The methods used by the two models to treat various aspects of the emission and dispersion are compared, and the best methods are selected, or alternatives are recommended where appropriate.

The latter portion of the report addresses the future needs. Because of the number of interrelated problems and decisions required to meet these needs, a systematic approach to the problem in the form of a "decision tree" is presented. The final section contains an outline of a proposed new computational system that should alleviate at least some of the problems identified in earlier sections. Two objectives were paramount in the new design: to make the model easier to use and to be able to implement the model on modern, small computers. Only the emission or front-end portion of the new system has been addressed in this report. The report concludes with recommendations for applications- and research-related tasks.

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Impact of Aircraft Emissions on Air Quality in the Vicinity of Airports

Volume III Air Quality and Emission Modeling Needs

Final Report

by

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Air Resources Section
Energy and Environmental Systems Division

January 1984

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PREFACE

This report constitutes Volume III in the series of reports entitled *Impact of Aircraft Emissions on Air Quality in the Vicinity of Airports.* Volumes I and II were published in July 1980 by the Federal Aviation Administration as FAA-EE-80-09A and FAA-EE-80-09B, respectively. Volumes III and IV summarize work performed under Interagency Agreement DTFA01-83-4-10556, between the U.S. Department of Energy/Argonne National Laboratory and the U.S. Department of Transportation/Federal Aviation Administration. This project was partially funded by the U.S. Air Force, Headquarters Air Force Engineering and Services Center, Tyndall Air Force Base, through a 1981 Memorandum of Understanding between the U.S. Air Force and the Federal Aviation Administration. The project officer was Mr. Howard M. Segal, Office of Environment and Energy, Federal Aviation Administration.

The last two volumes are entitled:

Vol. III: Air Quality and Emission Modeling Needs

Vol. IV: Nitrogen Dioxide and Hydrocarbons

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IMPACT OF AIRCRAFT EMISSIONS ON AIR QUALITY IN THE VICINITY OF AIRPORTS

VOLUME III: AIR QUALITY AND EMISSION MODELING NEEDS

by

Donald M. Rote

1 INTRODUCTION

Estimates of emission rates and atmospheric concentrations of various airborne substances in and around aviation facilities are required for determining compliance with regulations, testing the efficacy of potential control strategies, and a wide variety of other purposes.

Precisely how these estimates should be made, that is, what computational procedures should be used, has been the subject of both theoretical and field studies for over a decade. When the Airport Vicinity Air Pollution (AVAP) and the Air Quality Assessment Model (AQAM) were first designed some 10 years ago, for commercial and military facilities respectively, the major emphasis was on providing a user-oriented, state-of-the-art tool that would allow the user to treat virtually all sources of pollution with as much detail as he saw fit. The computer codes were developed and tested on large, relatively fast mainframe computers. It was assumed that the users' machines would be similar and that the users would have staff committed to the maintenance and operation of such complex computer codes on a long-term basis. Such staff were expected to be familiar with the aviation facilities, air-pollution regulations, and the principles of emission and air-quality computation.

Experience has shown that these user requirements were, in fact, too restrictive to permit as wide use as might otherwise be the case. Even though computer use has greatly expanded over the years, much of this growth has been in the area of the new, inexpensive microcomputers and minicomputers. Such machines, while convenient and easy to use, are not fast enough nor do they possess the necessary memory capacity to handle the AVAP and AQAM computer codes in their present configurations. Hence, the use of codes like these has neither grown with the use of computers nor with the need to perform emission or air-quality calculations. Therefore, along with the need to maintain these early codes and to periodically perform technical updates and refinements to keep pace with developments in the state of the art of modeling, there is also the clear need to design new versions that meet the needs and constraints of a greater number of users operating in the new environment of the microcomputers and minicomputers.

The purpose of the present report is to address the subject of modeling needs and how those needs can be systematically satisfied. It is noted that while some of these needs have already been met with existing models and their corresponding computer codes, others remain to be satisfied. The approach to this subject used here is essentially applications-oriented. It begins with a listing of the types of problems involving aviation facilities that are likely to require the use of computer models and then examines, in some detail, the technical characteristics of these problems that determine which features an applicable model must possess. The position is taken that it is the nature of the application, together with various user and machine requirements, that dictates the type of model to be used. Given this position, the ability of the currently available versions of the AVAP and AQAM computer codes to satisfy these technical and operational requirements is examined in detail. The strengths and weaknesses of these models and their computer codes and supporting documentation are noted. Various necessary and desirable changes to these models to make them applicable to a greater variety of problems, to update them, and to make them more usable are then discussed.

As a guide to possible future technical improvements, the procedures and algorithms used by the AVAP and AQAM computer codes are compared and the best procedures are identified. Where necessary, alternative procedures are recommended.

A "decision tree" is then presented as a systematic means of laying out some of the alternative courses of action that face the decision makers in trying to determine how best to resolve the discrepancies that exist between the present modeling needs and the current modeling capabilities, weaknesses, and limitations. Both separate and joint civilian and military agency alternative actions are presented.

Finally, the modeling-needs discussion ends with a presentation of a design of a new computational system that is proposed to satisfy one of the more important new user requirements not met by any current version of AVAP or AQAM. The new system is designed to be implemented on a small computer, which should greatly increase its usability by in-house agency staff.

The report is divided into 11 sections. The introductory section is followed, in Sec. 2, by a brief summary of types of potential problems requiring the use of computer models. Section 3 examines those technical characteristics of the various model applications that actually determine what features an applicable model should possess. The operational requirements for models are discussed in Sec. 4.

The AVAP model and its various currently available versions are described in Sec. 5, along with a summary and evaluation of its intended uses, strengths, limitations, and weaknesses. Updates needed to improve the model are also presented. The AQAM and its various versions are summarized in Sec. 6 using the same format as used for the AVAP model. Section 7 contains a detailed feature-by-feature comparison of the AVAP model and AQAM in which the best approaches or alternatives are identified.

The "decision tree" is presented in Sec. 8, and Sec. 9 is devoted to an outline of the proposed new joint computational system to be implemented on small computers. Section 10 is a report on a sensitivity study of emissions calculations. It is intended to provide some insight into the importance of including various source categories in an emission inventory of an air base or airport. Finally, Sec. 11 contains a summary and recommendations for future tasks needed to improve the current models from both the technical and user points of view.

2 POTENTIAL-PROBLEM TYPES AND MODEL USES

The two main problems of air-quality analysis are estimation of emission rates and computation of atmospheric concentrations. For some purposes it is sufficient to simply estimate the emission rates, while other problems require computation of the atmospheric concentrations as well. Examples of problems requiring emission estimates, but not necessarily atmospheric concentrations, are:

- Determining compliance with state implementation-plan (SIP) regulations or emission limits.
- Using rough-cut or screening procedures to determine whether a potential air-quality problem exists or could exist and whether a more detailed analysis is required.
- Estimating the overall effectiveness of emission-control strategies.

Civilian and military problems requiring computation of emission rates and/or atmospheric concentrations of various substances are generally either of a regulatory or research nature. There are also a number of specialized problems that pertain only to the military sector. These latter problems are essentially beyond the scope of the present discussion and are therefore only briefly referred to for completeness. Some potential model uses falling under the three main categories are listed below.

2.1 GENERAL RESEARCH PROBLEMS

Investigation of potential health and environmental impacts of pollutant emissions from various source types (recent interest has focused on photochemically reactive, odor causing, and hazardous airborne gases and aerosols). Some possible model uses are:

- An aid to assessing the nature and spatial extent of a particular impact or hazard.
- An aid to air-quality and emission data analysis and diagnosis of emission-inventory errors and deficiencies.
- Delineation of physical and/or chemical effects when complex mixtures of phenomena are involved.
- Development or refinement of special dispersion algorithms or submodels.

- Development and testing of simplified or "field" models.
- Identification of emission or air-quality "hot spots."
- Aid in design of field tests or experiments (e.g., monitoring-instrument deployment).

2.2 GENERAL REGULATORY-RELATED PROBLEMS

- Aid in performing regulatory-impact analyses.
- Determination of need for and efficacy of emission reductions.
- Evaluation of emission-control strategies.
- Preparation of preconstruction environmental impact statements (EISs) for new aircraft facilities or major modifications to existing facilities.
- Screening to separate cases that are not problems from those requiring more detailed treatment.
- Testing for compliance with local, state, and federal regulations (e.g., national ambient air quality standards [NAAQSs], SIPs, and prevention of significant deterioration [PSD] regulations).
- Calculations related to legal actions, citizen complaints, etc.
- Analysis of implications of proposed new regulations for aircraft operations, fuel use, engine design, thrust settings, etc.

2.3 SPECIALIZED MILITARY APPLICATIONS

- Investigations of dispersion of gases and aerosols of military importance, including obscurants, sprays, etc., in both terrestrial and maritime environments.
- Investigations of aircraft-plume dispersion in relation to detection using electro-optical sensors.

- Investigation of the dispersion of effluents from routine operations at rocket-launch, rocket-sled, and engine test facilities.
- Investigation of accident scenarios.
- Evacuation-corridor or hazard-zone prediction.

3 TECHNICAL REQUIREMENTS FOR MODELS

In view of the substantially different technical requirements for emission-rate and atmospheric-concentration computations, it is worthwhile to examine these requirements separately.

3.1 SOURCE-EMISSION-INVENTORY COMPUTATION REQUIREMENTS

The compilation of a source emission inventory tends to be straightforward but manpower intensive. The amount of manpower required is essentially directly proportional to the number of sources to be considered. For each individual source, the emission rate is generally the product of an appropriate emission factor (expressed in terms of mass of emissions per unit time per unit of source activity) and a measure of source activity. For automobiles, the unit of activity is vehicle miles (number of vehicles times number of miles traveled by each vehicle). For a single aircraft, the unit of activity is fuel flow rate at a particular thrust setting. In an airport or air base, aircraft activity generally refers to the number of aircraft of a given type in a given mode of operation (i.e., having a given thrust setting). In practice, because the emission factors for each pollutant depend on the particular type of source as well as on its mode of operation and fuel type, the emission rate calculations can become far too time-consuming and tedious to be performed by hand, especially when the source inventory is large. Furthermore, if a large number of tedious hand calculations are required, the chances of making errors are large and the effort required to check for and correct such errors is almost as laborious as the original hand calculations themselves. Hence, except in cases where only one or two isolated sources are being considered or where only net changes in total emissions due to a few changes in selected sources are being considered, it is highly desirable to have a source-emission-inventory computer model. The principal technical features required of such a model are listed below.

1. Up-to-date emission factors for all the criteria pollutants should be included for all of the sources likely to be encountered at an aircraft facility. These emission factors should preferably be based on actual source-emission measurements or, less preferably, on engineering estimates, and should be adjustable but protected from inadvertent adjustment by general users.

2. Emission rates for each source type should be calculated and stored on an hourly basis for subsequent processing or for use by dispersion models.

3. It may also be desirable, strictly for accounting purposes, to compute emissions on an annual or other long-term basis. For such purposes, landing and takeoff (LTO)-cycle-type emission factors should be employed.

4. For purposes of providing input data for dispersion calculations, it is necessary to provide hourly emissions for each physical source according to the source geometry (point, line, area).

5. Since civilian and military facilities use different operating procedures and service different aircraft types, it is probably most efficient to have separate but similarly structured emission models for the two types of facilities.

6. In view of the fact that, in some cases, pollutant concentrations may not be required and in order to reduce the overall computer requirements, it would be best to keep the emission models separate from the dispersion models.

7. Provisions should be available for the user to include treatment of aircraft, aircraft support or service equipment, access vehicles, and other facility mobile and stationary sources. The user should have the option to ignore any combination of these source types.

8. The spatial resolution requirement of source-emission inventories depends on whether dispersion calculations are required. For emission calculations only, the spatial-resolution requirements are generally minimal or nonexistent. For dispersion calculations, especially of the Gaussian-model type, the spatial resolution must be increased as the source-receptor distances of interest decrease. Generally, since public access is limited to certain areas of the airport, the spatial resolution requirement is not the same for all sources.

9. Airborne aircraft sources are generally regarded as insignificant compared to ground-based aircraft sources for ground-level pollutant concentrations. However, for purposes of source-emission-inventory completeness, or to test the significance of such sources, the user should be provided with the option of including or omitting them. In either case, the spatial-resolution requirement for such sources is not high. (See Sec. 10.3.)

10. Inclusion of evaporative nonmethane hydrocarbons (NMHC) sources should be optional. The spatial-resolution requirement for such sources is minimal. This follows for two reasons. First, these sources generally contribute only a small fraction of the total NMHC emissions from all sources (see Sec. 10.5). Second, the NMHC pollutant category is not governed by a health-related ambient-air quality standard and therefore does not require detailed source-receptor dispersion-model calculations. On the other hand, for purposes of emission-inventory completeness, or to assess their potential for contributing to photochemical smog, their inclusion may be warranted.

In addition to the above features, there are a number of other features that are required by an emission model if its outputs are to serve as inputs to other computer codes. Four types of codes that are of special interest are:

- Display codes that generate special forms of graphical and tabulated data.
- Statistical analysis packages.
- Source-oriented atmospheric-pollutant concentration models (including Gaussian-plume models).
- Grid or cell-type pollutant concentration models.

Special features that may be required by these codes are:

1. Detailed individual source descriptions, including source location and geometry. Such descriptions are required for source-oriented dispersion models, such as the Gaussian-plume-type models, if source effects on atmospheric dispersion must be taken into account (see Sec. 3.2.4). For such models it is convenient to separate the source geometries into points, lines, and areas. It is also necessary to provide the information needed to compute plume rise, if any, and initial plume size.

2. Time-dependence of source activity and emission rates. Hourly averages are adequate for most purposes.

3. Gridded emission rates (aggregated, for example, to uniform 1 km 1 km grid cells). These are required for grid or cell concentration models used, for example, for some photochemical-smog simulations. Gridded emission

rates may also be required for some types of display packages (e.g., contour-plotting packages).

Finally, it is important to recognize that emission rates for non-routine pollutants may be required for special purposes. A few of these purposes and their requirements are described below.

1. Calculation of NO and NO_2 concentrations requires separate emission rates for NO and NO_2, in contrast to the routine reporting of NO_x emission factors ($NO + NO_2$).

2. Calculation of photochemical-smog products requires separation of hydrocarbon emissions into several separate classes of compounds. The particular classification scheme to be used has not been uniquely defined as yet.

3. Calculation of visibility effects and odors requires estimates of emissions of selected gas and condensed-phase pollutants. The specific effluents of greatest concern have not been fully identified as yet.

4. Calculations of concentrations of special chemical aerosols of military or agricultural importance would also require appropriate emission rates but are best handled by special-purpose hand calculations rather than by general emission models.

3.2 AIR-QUALITY OR POLLUTANT-CONCENTRATION MODEL REQUIREMENTS

The second step in a detailed air-quality analysis, after the compilation of an emission inventory, is computation of pollutant concentrations for comparison with NAAQSs or other measures of significance. Because of the complexity of most problems, one or more computer models are usually required to perform these calculations. Although the term "dispersion models" has often been used to refer to such models, it is somewhat of a misnomer, since other phenomena besides atmospheric dispersion must often be considered in the calculation of atmospheric-pollutant concentrations. Hence, a more appropriate term would be air-quality or pollutant-concentration models. The specific type of air-quality model required by civilian and military users depends largely on the nature of the application, rather than on the user per se. Several general features of applications that determine the corresponding modeling requirements are described below.

3.2.1 Level of Detail

The main issue regarding the level of detail required of a particular application is whether a screening or a detailed air-quality modeling calculation is required. For regulatory applications, it is often useful to determine whether or not a potential problem exists. This can be done through application of a conservative screening procedure. If a potential problem does exist, then a more detailed analysis may be required.

The main requirement for a screening procedure, aside from ease of use, is that it be conservative. That is, it must provide an upper bound to the magnitude of the emission rates and/or atmospheric concentrations. The closer this conservative upper bound is to the expected maximum value, the better. However, caution is always required in applying screening tools, since they may be overly conservative, in which case a need for more detailed analysis may be indicated more often than is really necessary. On the other hand, because of the inherent simplicity of screening procedures, they may fail to treat those aspects of a particular problem that are most important. The applicability of screening procedures and the interpretation of the results should always be subjected to expert review.

Another issue of importance is whether it is necessary to treat individual sources in detail or whether it is satisfactory to aggregate source emissions up to some less-detailed level. Generally, the level of detail required for the treatment of source configurations is determined by the relevant source-receptor distances. If these distances are relatively large compared with the intersource separation distances of comparable sources, the sources can be aggregated. However, if one is interested in studying the contributions of selected source types, or if adjacent sources have physically different characteristics, then individual source treatment may still be required.

3.2.2 Temporal and Spatial Scales

The temporal- and spatial-scale combinations pertinent to four general types of applications are displayed in Table 1. Note that the NAAQS-related applications involve hourly to annual averaging times. In spite of the fact that the shortest averaging time for NAAQSs is one hour, it is important to realize that for some substances atmospheric concentrations are governed by phenomena having much shorter characteristic times. For example, NO interacts within seconds to form NO_2 in the presence of ambient levels of O_3. Hence, simulation time scales that must be treated in a model may differ from the required output time scales and depend largely on the characteristics of the air-quality variables of concern.

Spatial scales are not specified in the NAAQSs, but it is unlikely that the public would routinely be closer than a few hundred meters to military or civilian aircraft activity. Hence, the near-field, source-dominated turbulence zone is usually not subject to the NAAQSs. However, this zone may be subject to occupational health and safety standards. At the other end of the spatial scales are the long-range transport processes, including global-scale processes. It is unlikely that aircraft operations will contribute significantly to ground-level concentrations on scales greater than tens of

Table 1 Temporal- and Spatial-Scale Combinations Relevant to Air-Quality Problems[a]

	Spatial Scales				
Temporal Scales (averaging time)	Up to 10s of Meters[b]	10s to 100s of Meters[c]	100s of Meters to 10 km[d]	Up to 100s of Kilometers	Global Scale
Fraction of an hour or continuous	1,3,4	1,3,4	1,4	0	0
1 Hour	1,3,4	1,2,3,4 (AVAP?, AQAM?)	1,2,4 (AVAP, AQAM)	1	0
3-24 Hours	1,3,4	1,2,3,4 (AVAP?, AQAM?)	1,2,4 (AVAP, AQAM)	1	0
1 Month to 1 Year or More	1,3	1,2,3 (AQAM?)	1,2,4 (AQAM)	1	1

[a] Problem-type code:

0 Not applicable
1 Research
2 Regulatory -- NAAQS
3 Regulatory -- Occupational Safety and Health Administration (OSHA)
4 Special military.

[b] The region in which source characteristics significantly affect or dominate dispersion.

[c] The transition region in which ambient atmosphere plays an increasingly important role in dispersion but in which single events or sources remain distinguishable.

[d] The airport or air-base vicinity (urban scale) in which multisource contributions dominate.

kilometers except in special cases. One special case of considerable concern over the past decade has been the NO_x contributions of high-flying aircraft to upper tropospheric and lower stratospheric phenomena. These applications are beyond the scope of the present report.

Table 1 also shows which scale combinations are applicable to the AVAP model and AQAM. The entries with question marks mean the applicability of the models is not certain.

3.2.3 Source Configuration

Source configuration refers both to the spatial distribution of the sources of interest relative to the receptors and to the geometry of individual sources. The spatial distribution and number of sources is important for several reasons. First, if the number of sources is large, machine-oriented computational procedures are almost certainly required to reduce the tedium involved and to reduce the likelihood of making errors. Second, the distribution of source types determines, to a large extent, whether source-by-source or aggregated source analysis is needed. In addition, in cases where emissions from adjacent sources tend to overlap (e.g., overlapping aircraft plumes), it may be necessary to investigate the consequences of that overlapping in detail. If the pollutant of interest is relatively inert, the overlapping can be handled by a simple superposition of contributions from individual sources. However, if the emissions are reactive, then the simple superposition principle may not apply and some alternative to the simple addition of single-source contributions may be called for.

Sources are generally divided by geometry into line sources, point sources, and area or volume sources. Line sources are complicated by the fact that their orientation relative to wind direction and ground level must be taken into account. In addition, if a line-source geometry is chosen to represent a runway, then, since the aircraft operating on the runway move at nonuniform speeds, the emission density along the line source will be correspondingly nonuniform.

In view of the importance of line-source geometries for simulating aircraft operations, the greatest attention to detail and accuracy is required of line-source pollution-concentration models. However, in the case of routine air-quality problems, it has been demonstrated that for ground-level concentrations, airborne aircraft emissions are not very important. Hence, it is not necessary to provide detailed model treatments of elevated-aircraft line sources. (See Sec. 10.3.)

Finally, as noted earlier, spatial-scale and source configuration are closely linked. As the spatial scale is increased, less attention to details of the source configuration is required. This suggests that, since NAAQSs generally apply only to locations well removed from aircraft, one can avoid detailed treatments of aircraft plume dynamics for such regulatory applications. This is a dangerous assumption, since for some cases such phenomena as initial plume dispersion, plume rise, and enhanced vertical plume dispersion can have significant impact on downwind concentrations. It is therefore important to carefully examine the level of treatment of plume dynamics required before proceeding with a particular application. Theoretical investigations, including sensitivity tests with more sophisticated models, are perhaps the only sound ways to provide guidance on this issue.

3.2.4 Source Effects

Applications requiring data on atmospheric concentrations near sources require that models provide reasonable treatment of source effects such as:

- Building and stack downwash and wake effects.
- Aircraft and aircraft-engine-generated turbulent wake effects.
- Plume rise and enhanced vertical dispersion.

Such effects influence both the plume trajectory and its initial dispersion, and therefore significantly affect the near-field concentrations.

3.2.5 Pollutant Characteristics

The following pollutant characteristics play a dominant role in determining the modeling requirements for a particular application:

1. Pollutant-reactivity time scale relative to the time scale of the problem (e.g., hourly average concentration).
2. Primary vs. secondary pollutants.
3. Phase (gas, liquid or solid aerosol).
4. Buoyancy.

Pollutants that are emitted directly into the atmosphere from sources are called primary pollutants. Some pollutants, such as CH_4 or nonreactive hydrocarbons, are relatively inert over time scales of hours, while others, such as CO, are relatively inert over time scales of days; NO, on the other hand, reacts on the time scale of seconds with background ozone. In cases in which travel times are short compared with reaction times and concentration averaging times are no more than one hour, a number of pollutants, including CO, CH_4, nonreactive hydrocarbons (and some moderately reactive hydrocarbons),

SO_2, and NO_x ($NO + NO_2$) can be treated as though they were inert. Consequently, they can be handled with nonreactive pollutant concentration models.

Secondary pollutants, such as NO_2 (some NO_2 is also primary), fine-particle aerosols, some photochemical-smog compounds, and ozone are produced from interactions between primary pollutants (gases and vapors) and background atmospheric constituents. Since their formation time scales vary from seconds, for NO_2 conversion from NO in the presence of ozone, to an hour or more, for the formation of photochemical-smog constituents, and hours to days for formation of sulfate aerosols, the modeling requirements depend quite strongly on the particular pollutant of interest. Whereas the NO to NO_2 conversion process can occur within an individual aircraft plume, many of the photochemical-smog-formation processes and aerosol-forming processes occur long after the individual plumes have merged with each other and with background pollutants. Hence, photochemical-smog models are generally required to operate over urban to interurban spatial scales, while sulfate models involve long-range transport over hundreds to thousands of kilometers.

The pollutant's phase, that is, whether it is a gas or condensed liquid droplet or solid particle, affects the pollutant transport in the atmosphere and its rate of deposition onto surfaces. Whereas particles with diameters in excess of 10 μm tend to be removed rather rapidly due to gravitational settling, those with diameters less than 1 μm are deposited out only very slowly. In addition, many pollutants can undergo phase changes over periods ranging from minutes to hours, depending upon the pollutant species involved and the concentrations. These phase changes affect not only the subsequent dispersion but other properties that may be of concern.

The buoyancy of a pollutant plume released into the atmosphere can be positive, neutral, or negative. Positively buoyant pollutant plumes rise in the atmosphere until they reach thermodynamic equilibrium with the surrounding air. Thereafter they are dispersed by ambient turbulence and wind. Aircraft exhaust plumes are positively buoyant, but are mixed with substantial engine- and aircraft-wake-generated turbulence. This "internal" turbulence dominates the near-field dispersion until it is quenched by entrainment of background-dominated turbulent air. Neutrally buoyant plumes are produced by sources that emit pollutants near ambient temperature and density. Negatively buoyant plumes can result from evaporation of cryogenic liquids, or from highly concentrated emissions of pollutants having molecular weights greater than that of air, or from special conditions involving gas-aerosol phase equilibria (as in the case of ammonia). Negatively buoyant plumes often pose special hazards because higher-than-normal concentrations can persist near ground level for longer periods because of the suppression of the dilution that would occur in neutral or positively buoyant situations. Special attention to source conditions is required to determine whether or not negatively buoyant conditions apply.

Commercial aircraft sources are unlikely to yield negatively buoyant plumes. However, hypergolic fuels are sometimes carried by military aircraft and are often stored and transported in military facilities and are subject to accidental releases. Treatment of negative buoyancy effects is beyond the scope of the present study.

3.2.6 Air-Quality Variables

The type of air-quality model and its specially required features depend on which air-quality variable the particular application calls for. Some applications require concentrations of primary pollutants and others may be concerned with secondary pollutants or derived quantities. Since secondary-pollutant concentrations depend upon one or more conversion processes, their simulation can be quite difficult. Derived quantities represent a third class of air-quality variables of concern in some applications. These quantities are generally properties of primary or secondary pollutants. Examples are atmospheric extinction or related quantities (visibility, obscuration), zones of flammability or detonability, odor levels, etc. Since these properties do not themselves control the pollutant concentration, they can be dealt with by algorithms appended onto pollutant concentration models. Hence, *applications* calling for derived quantities require a pollutant concentration model plus an appropriate algorithm to yield the required property of interest in the application.

3.2.7 Terrain Characteristics

Most air-quality models work best for relatively flat, uniform terrain. Flow patterns in complex natural terrains, shoreline environments, and around man-made structures generally cannot be accurately simulated with simple pollutant concentration models. Special flow models are usually required for such applications. Fortunately, however, most civilian and military applications are confined to relatively simple terrain conditions. Two exceptions are worth noting: first, on a small spatial scale, local wake effects due to the source structures themselves or to nearby structures can lead to significant changes in wind flow and in concentration patterns. For applications requiring pollutant concentrations that are likely to be influenced by wakes from structures, field measurements or parametrizations based on physical modeling are most desirable. Pollutant concentration models should include parametrizations to handle such cases. Second, on a larger spatial scale, shoreline environments can exhibit special transport and dispersion conditions. In many cases such locations are associated with periodic recirculation patterns resulting in pollutant accumulation over a several-day period, as in the Los Angeles Basin. In addition, marine inversions can result in fairly shallow mixed layers and higher-than-expected inland pollutant concentrations. The recirculation problem cannot be dealt with using simplified models. The effects of shallow mixed layers can be effectively handled using simplified models provided that an adequate description of the particular region of interest is available and meteorological data sufficient to characterize typical and worst-case conditions can be obtained. Careful accounting of the diurnal pattern of the shoreline meteorology is usually required. In some cases it is possible to simulate the shoreline meteorology itself, although this type of simulation is generally beyond the scope of the usual pollutant concentration models.

3.3 METEOROLOGICAL REQUIREMENTS

Computation of atmospheric concentrations requires meteorological data either on a short-term (generally hourly) or on a long-term statistical basis. Typical short-term data required by source-oriented models include wind speed, wind direction, depth of the mixed layer, and some measure of the turbulent properties of the atmosphere, such as the Pasquill-Gifford-Turner (PGT) stability class.[1] For the simpler models, one representative meteorological monitoring station is required. This assumes that the region of model application is fairly uniform with respect to terrain features and surface roughness.

Several points are worth noting. First, even in cases where only moderate variations in terrain exist, the near-surface wind field can depart significantly from spatial uniformity. Second, the original PGT atmospheric-stability classification scheme has been under review for a number of years, and the American Meteorological Society (AMS),[2,3] in particular, has recommended some alternative schemes that require additional meteorological data. In cases where the additional data are not available, calculational procedures based on theoretical considerations and meteorological field experiments have been proposed.[4] This second alternative is, unfortunately, not guaranteed to produce more satisfactory results than the original scheme. (This latter point has not been adequately addressed in the literature.)

Third, estimates of the depth of the mixed layer are often not readily available to model users. Provided that the transport distances, or spatial scale, of the application are not more than a few kilometers, the depth of the mixed layer is not too critical unless it is relatively small, say a few hundred meters or less. Unfortunately, such low mixing depths can occur near shoreline environments and can often occur in other environments for periods of one or more hours in the morning and sometimes for more extended periods during the evening and nighttime hours under the influence of urban heat-island effects. Consequently, for worst-case calculations, it is important to obtain at least reasonably good representative estimates of the mixed-layer depth as a function of time of day.

4 OPERATIONAL REQUIREMENTS FOR MODELS

Operational requirements placed on computational procedures for estimating emissions and atmospheric concentrations include usability, compatibility with available computer hardware, and documentation. Of these three, usability has come to be recognized as a requirement of paramount importance. Users, of course, prefer to work with simple models that do not require extensive familiarity with technical detail or manpower-intensive data compilations. At the same time, it is recognized by users that the nature and technical characteristics of air-quality-related problems cover a fairly broad spectrum. Hence, flexibility is also an important requirement of a model.

The rapid growth in the use of desk-top terminals together with minicomputers or microcomputers has led to the need for highly efficient computer software that requires little central processing unit (CPU) time and core storage. This requirement is generally inconsistent with large, complex, flexible computer codes unless those codes can be redesigned in a modular format.

Another aspect of usability is the choice of interactive- or batch-mode operation. In the interactive mode, the user sits at a computer terminal and responds to a series of questions or prompts issued by a user-interactive computer program. The user's responses provide the inputs needed by the program to perform the computation. In the batch mode, the user prepares a deck of cards or a computer file containing all the necessary input data. This preparation is generally done by following a series of directions provided by a user's manual. Once the input file is completed, the user submits a job that requires the computer program to read in the input information and perform the calculation. The process of submitting a job involves reading the deck of cards into the computer or keying in a brief set of instructions via a computer terminal.

From the point of view of the user, the interactive mode is often preferred. This is especially true for users having little or no familiarity with the computer program. Beginning users tend to be intimidated by user's manuals that require detailed study prior to using the computer program. In the interactive mode, the uninitiated user can often begin "playing" with the computer program with little or no preliminary study of documents. However, for serious computations the differences in effort required may turn out to be quite small.

The disadvantages of the interactive mode are that the user-interactive program must, of necessity, contain substantially more programming instructions than a program written for batch-mode operation. This means more core storage and longer running time. In addition, in order to remain within the limitations of particular computer installations, it may be necessary to limit the number of options available to the user and therefore limit the flexibility and degree of sophistication of the main computational parts of the computer program. Furthermore, for large problems, it may prove tiresome to remain at a computer terminal for long sessions using the interactive mode and preparing long streams of input information.

One way to avoid long interactive terminal sessions is to use input-file editors. These are programs that permit the user to modify existing large input data sets without having to redevelop the data sets from scratch.

The problems of limited core storage and run time, as well as the problem of limited options or flexibility, can be overcome by designing mixed-mode computer programs that can be executed in parts. For example, it may be desirable to divide a computer program into two or more components. The first component, which takes in and organizes the input data, could be operated in the interactive mode, and the second part, which contains the main computational algorithms, could be designed for operation in the batch mode. In addition, for increased convenience the first part could be supplemented with an editor program that could be used to make modifications to existing large sets of input data. The overall structure of such a package of computer program components would look something like the macro flowchart shown in Fig. 1. Note that in this flowchart an additional component for creating various output displays is also illustrated. For increased flexibility or to accommodate varying technical requirements of different applications, several alternative computational program components could be substituted, provided that their input and output structures were compatible with the other program components.

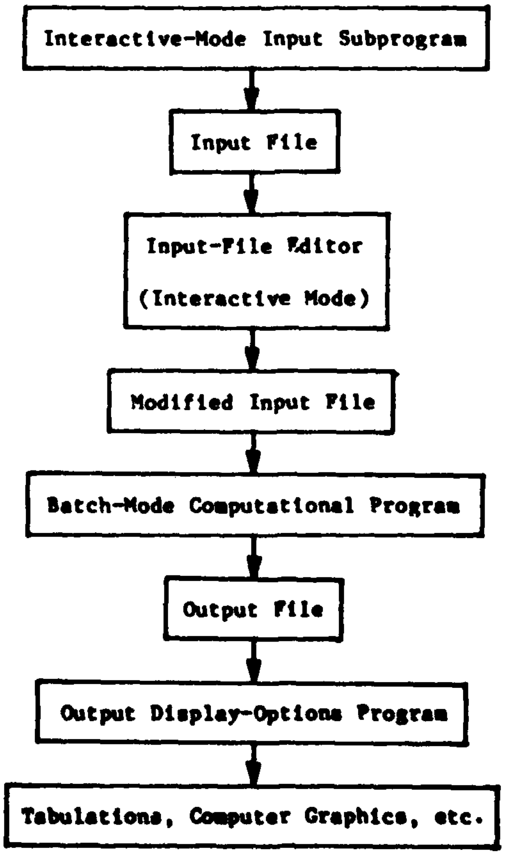


Fig. 1 Macro Flowchart of a Mixed-Mode Computer Program

A final operational requirement for a computational system is good documentation. Generally, the documentation should consist of the following parts:

1. A description of the intended uses of the program.

2. A technical description of the equations and algorithms used and a tabulation of the important parameters and constants.

3. A description of the computer programs, including a macro flowchart and descriptions of all subroutines; possibly also detailed flowcharts and/or program listings.

4. A detailed user's manual that includes guidance in selection of various options, if there are any.

5. An example problem that can serve as a guide to the user as well as a benchmark for comparison with results obtained by the user on his own computer facilities.

5 SUMMARY AND EVALUATION OF THE AVAP COMPUTER MODEL

The two main models developed specifically for military and civilian air-quality problems involving aircraft are the AQAM and the AVAP model, respectively. These models were originally developed in the early 1970s and have subsequently undergone various modifications, refinements, and updates. In Secs. 5 and 6, the AVAP model and AQAM, along with their various modified versions, will be discussed in detail. Their intended uses and strengths, as well as their limitations and weaknesses, will be described. Comparisons will be made in Sec. 7, and the best features of each model will be indicated for possible future incorporation into a proposed joint civilian/military modeling package (see Sec. 9).

5.1 THE AVAP MODEL

The AVAP model was originally intended for evaluating the air-quality impacts of large civilian airports. The overall structure of the model is illustrated in the macro flowchart shown in Fig. 2. All of the components illustrated in this chart are contained in a single computer program composed of a number of subroutines and a main driver. Both the emission-inventory and dispersion algorithms are contained in this package and are executed together in the batch mode. The outputs can be generated in printed formats or punched cards or stored on magnetic tape for future use. The user can choose any configuration of airport he wishes, including several runways and associated taxiways, gate areas, etc. In addition he can define aircraft, airport-nonaircraft, and environ sources, and can designate any of these as point, line, or area sources. The line sources can have arbitrary lengths and orientations in three dimensions. The model is designed to compute emissions and atmospheric concentrations of relatively inert pollutants on an hour-by-hour basis in 24-hr cycles. The model was not designed to compute long-term averages. However, long-term averages can be computed by combining the hourly-average values either in sequence or in some statistical fashion.

A uniform receptor grid and/or a set of specially located receptors can be defined by the user. To allow the model to be applied to an arbitrary runway configuration, the user is asked to specify runway operations in terms of four 90° wind quadrants. These quadrants can be arbitrarily oriented, but the user must define the wind-quadrant orientation angle that measures the orientation relative to geographic north. (This angle should be between 0° and 90°.) Then, for each of these four wind quadrants, the user must allocate, for each class of aircraft, the runways that are available for arrivals or departures. This user-supplied information allows the computer model to determine which runways are being used during each hourly set of meteorological conditions for each aircraft class.

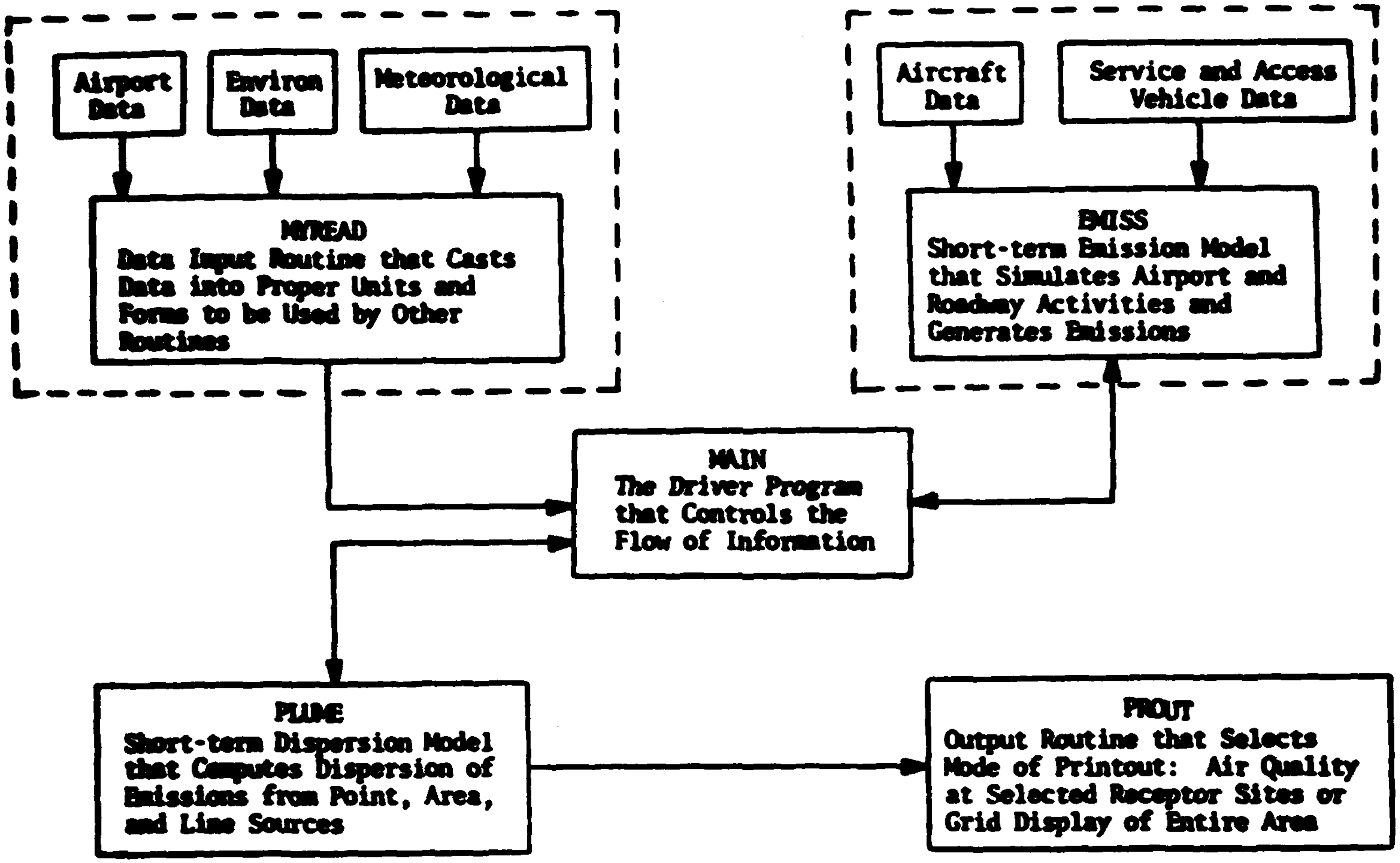


Fig. 2 Overall Structure of the Airport Vicinity Air Pollution Model

The simulation of both airborne and ground-based aircraft operations is based on an aircraft classification scheme that is described in the user's manual. This scheme can be altered by the user, provided the alterations are done in a self-consistent manner. The classification scheme is described in the next several paragraphs.

Each aircraft type, such as a B727 or DC10, is assigned a "Type Index" value. The arrival rate is given by the user in terms of the number of arrivals of each aircraft type per hour to the airport. Service-vehicle types and their operating times are also given in terms of the aircraft "Type Index." To each aircraft type is assigned four additional indices: Aircraft Class, Aircraft Range, Number of Engines, and Engine Type.

The Aircraft Class Index is used by the computer model, together with the hourly wind direction, to assign takeoff and landing runways and outbound and inbound taxiways. Runway availability is specified, as already mentioned, by the user input data in terms of four wind quadrants and aircraft class. (Taxiway availability is determined by runway and airline or gate position.)

The Aircraft Range Index is used to assign certain aircraft operational parameters, including taxi speed and times-in-mode. The numbers and types of engines are used to assign pollutant emission factors. An example of the classification scheme, which was used in the example problem in the AVAP user's manual,[5] is shown in Table 2.

The airborne operations simulated in the model include one approach path (defined by the user) and one or two departure paths (defined by the user) for each runway. These airborne optional paths are not Aircraft-Class dependent except to the extent that the runways themselves are Aircraft-Class dependent.

One diurnal aircraft arrival pattern is provided by the user for each aircraft type. To simplify the amount of input data required, the model applies the same pattern to all airlines employing a given aircraft type.

5.2 EXISTING VERSIONS OF AVAP

The original version of the AVAP model is from circa 1973. It has been published by National Technical Information Service (NTIS), is available on magnetic tape, and has been well documented with both technical reports,[6,7] validation study reports,[8,9] and a user's manual.[5] The user's manual contains benchmark runs and an example application to Washington National Airport (DCA) to help aid the user. The source-emission factors and source-activity algorithms were developed from published data and airport observations dating from 1969 to 1973. The aircraft types treated in the model have not changed appreciably from the NTIS publication (which appeared in 1975-1976) to present times.

Table 2 Aircraft Classification Scheme Used in the Example Problem in the AVAP User's Guide

Aircraft Type	Aircraft Model	Aircraft Class	Aircraft Range	Engines per Aircraft	Engine Type	Engine Model[a]
1	Boeing 727	4	3	3	3	JT8D
2	Douglas DC9	4	3	3	3	JT8D
3	Boeing 737	4	3	3	4	JT8D
4	Convair 580	5	3	2	5	A-501-D13
5	BAC 111	7	3	2	6	Spey-511
6	NAMCO YS11	5	3	2	5	A-501-D13
7	Beech 99	6	4	2	4	TPE331
8	Fairchild FH-227	5	3	2	5	A-501-331
9	Twin Otter	6	4	2	4	TPE331
10	Piston Engine	9	4	2	7	0-320

[a] Aircraft engine models for which no emissions data are available are replaced by models having similar characteristics.

A simplified version of AVAP that will be referred to as the "abbreviated version" (circa 1975) was developed as an alternative to the full AVAP model for screening applications. While the dispersion algorithms remained virtually unchanged, the input structure was considerably modified, and far fewer options were made available to the user. The abbreviated version is much easier to use, since most of the decisions have been "internalized." Only one runway-taxiway-terminal area configuration is available, and no sources outside the airport (environ sources) are permitted. The model computer code is available through the FAA and has been documented with a detailed but unpublished user's manual.[10]

An updated version of the original, or NTIS-published, version of the AVAP model was prepared and applied to the assessment of air-quality impacts at four major U.S. airports around 1980. This version, which will be referred to as the "updated version," has not been formally published or extensively documented. However, a description of the model, along with the results of the air-quality assessment mentioned above, has been reported in three documents.[11-13] The updated version contains updates to both the emission and dispersion algorithms. The updates are based on new emission-factor data published by the Environmental Protection Agency (EPA), observations of aircraft operations at several major airports, and field programs involving meteorological and air-quality observations at Dulles International Airport and Washington National Airport.[12]

5.3 COMPARISONS AMONG AVAP VERSIONS

For convenience, the three versions of AVAP mentioned above will be designated as follows:

Version 1: Original NTIS version, circa 1973

Version 2: Abbreviated version, circa 1975

Version 3: Updated version, circa 1980

Comparisons can be conveniently made in the categories of overall structure, input structure and user options, emission parameters, dispersion algorithms, output, and documentation.

5.3.1 Overall Structure

The three versions all contain both the emission and dispersion algorithms and are operated in the batch mode.

5.3.2 Input Structure and User Options

The input structures of the three versions are different. Versions 1 and 3 are quite similar except for one important difference. Whereas Version 1 requires only the arrival rates as input, Version 3 also requires the departure rates as input. Version 1 incorporates an empirical algorithm that takes into account aircraft turnaround time and overnight parking to calculate departure rates. This procedure was followed because, at the time of program development, only arrival times of aircraft were readily available from the commercial airline guide. Because of the influence of overnight aircraft parking, Version 1 performs calculations in 24-hr cycles (as many as the user chooses). Version 3, on the other hand, makes use of both user-supplied arrival data and departure data available from more recent issues of the commercial airline guide. Hence, Version 3 can be operated on an hour-by-hour basis. Also, Version 3 contains updated emission factors and updated times-in-mode for aircraft sources. These updates do not, however, constitute changes in input structure, merely changes in input parameter values.

Version 2 requires only arrival rates as inputs, but it assumes that the number of arrivals during a given hour equals the number of departures. Version 2 performs only one one-hour computation at a time. Version 2 also differs from Version 1 in a number of other significant ways. Whereas Version 1 permits the user to specify a great variety of aircraft, airport-nonaircraft, and environ sources with point, line, and area geometries, the choices permitted by Version 2 are very limited. In Version 2 the user can use at most one runway, one inbound apron, one inbound taxiway, one outbound taxiway, one outbound apron, up to 60 access-vehicle straight-line roadway segments, one aircraft area source, and one nonaircraft area source.

The aircraft area source includes emissions from four source types:

1. Aircraft ground-service vehicles.

2. Auxiliary power units (APU) on aircraft.

3. Aircraft taxiing within the area.

4. Aircraft engine idling within the area.

In addition, whereas in Version 1 the user must supply most airport and aircraft source parameters, this burden is largely removed through the use of default values provided in Version 2. The user has the option of overriding up to 23 defaults simply by entering 1's in the appropriate columns of a default control card and then adding the necessary input cards containing his own values.

5.3.3 Emission Parameters

The emission parameters for nonaircraft airport and environ source types are identical for all three versions. (Version 2 does not treat environ sources.) The aircraft emission factors are the same in Versions 1 and 2 but have been updated in Version 3 to 1977 values.

5.3.4 Dispersion Parameters and Algorithms

The dispersion parameters and algorithms in Versions 1 and 2 are identical. There are several differences in Version 3. These are:

1. An empirical plume-rise equation based on the Dulles 3-Tower Field Experiments was introduced into the taxi-idle aircraft mode.

2. New initial plume dimensions based on the Dulles and Washington National experiments were used.

3. Initial plume dimensions were incorporated into the runway, taxiway, and apron line sources using the addition of variance in lieu of the virtual-point-source method. All other source types used the virtual-point-source method.

4. Enhanced vertical dispersion due to plume rise was incorporated into the treatment of all sources.

5. Only downwind-distance-dependent vertical-dispersion parameters were used, in lieu of the maximum of the above parameters and the time-dependent vertical-dispersion parameters.

5.3.5 Output

The model outputs were changed in Version 3 to provide additional emission and concentration information. In addition, the output was modified to insure compatibility with a contour-plotting package.

5.3.6 Documentation

Version 1 has technical documentation, model validation-study documentation, and a user's manual, all published by FAA. Version 2 has only an unpublished user's manual. Version 3 has supporting technical documentation but no formal model documentation or user's manual.

5.4 AVAP MODEL EVALUATION

5.4.1 Intended Uses and Strengths

Version 1 (original NTIS version) was intended to be used to assist in (1) preparation of EISs for new construction, (2) modification of existing airports, and (3) evaluation of alternative strategies for emission control. Examples of changes in airports that could be analyzed include fuel-use changes, changes in the physical airport layout (additions of taxiways, runways, access-vehicle roadways, etc.), growth in operations, and environ source changes. In Version 1, the user is provided with a great deal of flexibility regarding his choice of airport operating parameters, emission factors, and treatment of source types in terms of points, lines, or areas. Listings of parameter values are provided in the user's manual, but the user can use alternative values if he feels they are more suitable for his particular application. However, regardless of whether or not he uses the values listed in the user's manual, the values he uses must be entered into the computer.

In Version 2 (abbreviated version), most of the parameter values are provided as automatic defaults that do not have to be entered by the user. If the user wants to override these default values, then he must provide additional input information. Version 2, however, is intended only as a screening tool to obtain a rough idea of the air-quality impacts that might occur if all airport operations were confined to a simple configuration consisting of only 1 runway and a few other distinct sources. Hence, Version 2 does not provide nearly as much flexibility to the user as Version 1 does.

All three versions of AVAP permit the user to readily update emission parameters. Many of these parameters require periodic updating or adjustments to account for facility-to-facility variations. All three versions are designed for operation in batch mode and combine emission and dispersion calculations in a single computer code. Consequently, while they are not "user-friendly" in the sense of an interactive code, they are more efficient to operate, especially on large problems, and do not require the long terminal sessions characteristic of large interactive codes.

The Version 1 dispersion algorithms are designed to provide a somewhat conservative estimate of relatively inert primary-pollutant concentrations. Pollutants such as SO_2, CO, NO_x, HC or NMHC, and total suspended particulate (TSP) can be considered. No chemical or physical transformations are considered, and no removal processes, such as wet or dry deposition or gravitational settling, are accounted for.

The dispersion parameters correspond to greater dispersion rates than those used in Turner's *Workbook of Atmospheric Dispersion Estimates*[1] because they are adjusted for one-hour sampling times and urban dispersion conditions. Comparisons indicate that they more closely represent field observations. The absence in Versions 1 and 2 of any treatment of plume rise or enhanced vertical dispersion from aircraft sources leads to overestimates of concentrations near such sources. This problem is partially corrected in Version 3, which does account for these effects for slow-moving aircraft. The treatments of these effects in Version 3 is based on the Dulles 3-Tower Field Experiments.[12]

The AVAP model incorporates simple treatments of building and stack downwash and wake effects and aircraft wake and jet turbulence effects. Briggs' "rules-of-thumb"[14] are used to indicate when the building and stack effects are likely to occur, and such effects are expressed in terms of reduced plume rise and/or enhanced initial plume dispersion. Finite initial plume sizes are handled with the virtual-point-source method. Aircraft jet-wake and turbulence effects are similarly treated by enhanced initial plume dispersion. The parameters used for this purpose in Version 3 are based on the Dulles and DCA Airport Field Experiments.[12] No attempt is made to treat these complex phenomena in detail in the near field. The model applies only after the plumes become passive objects influenced by ambient atmospheric turbulence. Hence, the model should not be used to estimate concentrations too close to large structures or aircraft.

Complex terrain effects are ignored in AVAP. The use of this model in valley situations or near shorelines is not advised unless the effects of these features are well known. The models are applicable to nearly flat regions on the order of 10-20 km on a side.

Since all versions assume steady-state conditions, that is, constant emission and dispersion rates for at least one hour, transient phenomena cannot be accounted for. Repeated transient phenomena, such as aircraft takeoffs, are treated as though their air-quality impacts could be averaged over one hour. This treatment is satisfactory only for relatively inert pollutants and averaging times on the order of one hour. Such a procedure must be modified for situations where shorter averaging times are required. Also, fairly reactive and/or secondary pollutants or highly variable meteorological conditions require more detailed treatments.

5.4.2 Limitations and Weaknesses

Limitations and weaknesses are not always perceived as such by various users. Sometimes a limitation may be regarded as a blessing. Nevertheless, an attempt has been made to list what may be regarded by some, at least, as shortcomings of the various AVAP versions. These are discussed under the three separate headings of Usability and Availability, Documentation, and Technical Issues.

Usability and Availability

Version 1 tends to be hard to use because its application requires a careful review of the user's manual. In addition, for large problems, a considerable amount of input data must be prepared by the user. Version 2, however, provides many default values and alleviates much of this problem. However, this reduction in input preparation time is achieved at the expense of flexibility and accuracy of representation of actual airports. Of the three versions, only Version 1 is readily available through NTIS.

Because the emission and dispersion algorithms are combined into a single package, and because of the options regarding source inputs, the AVAP codes all require rather large computer core storage. In addition, the algorithms are not optimally written and therefore can consume significant amounts of computer time, especially when large numbers of repetitive calculations are involved. Hence, these codes require fast, large, mainframe computers. Also, it is inefficient to use them on small problems involving only a few sources.

Documentation

The documentation of Version 1 was quite adequate from both the user and technical points of view at the time it was prepared. However, many of the emission parameters either listed in the user's manual or incorporated as defaults into the emission model are outdated. In addition, technical changes have been incorporated into Version 3 that have not been adequately documented. Further improvements have also been planned but have not yet been thoroughly documented.

Technical Issues

No treatment of reactive or secondary pollutants (e.g., reactive hydrocarbons, NO_2, O_3, or secondary fine particulate matter) is available. NO to NO_2 conversion is not treated. Aerosol formation is not treated. There is no treatment of complex terrain features. Applications are limited to an airport and its near vicinity. Only neutral and positive buoyancy are treated. Treatment of individual aircraft plume dynamics is not adequate tor research studies of near-field phenomena (although such effects may not be relevant for EIS-type applications). Building-wake effects are not adequately treated to provide reliable estimates of concentrations near terminal buildings. Nonaircraft emission factors are out of date. Plume rise in takeoff mode is not treated. Only Carson-Moses and Holland plume-rise formulas (see, for example, Ref. 15) are currently available as options for nonaircraft sources. No treatment of calm conditions other than persistence of preceding or following nonzero wind conditions is included. The present line-source algorithm is inefficient and has been shown to be inaccurate under certain special input conditions. The dispersion parameters are based on earlier dispersion modeling studies and the PGT stability classification scheme. The recent recommendations of the AMS should be evaluated and considered for incorporation into the AVAP models. Currently, the user must either supply a value for the depth of the mixed layer or choose the default procedure,[16] which is based on the Holzworth climatological value for the region. Some alternative, more adequate default procedure should be developed. Specific jet-engine thrust settings are assumed to correspond to aircraft operational modes. These may require updating.

5.4.3 Updates Essential for Inert-Pollutant and/or Screening Applications

Updated, faster, more accurate line- and point-source dispersion algorithms should be incorporated. Updated documentation to include the latest improvements in algorithms and various parameter values should be added. Dispersion parameters and the turbulence classification scheme should be updated. Updating of the aircraft plume-rise algorithm and initial-dispersion parameters for all aircraft modes, especially takeoff, is needed.

5.4.4 Additional Updates Desirable for Inert-Pollutant and/or Screening Applications

If nonaircraft sources are to be considered, emission factors should be updated. If calm conditions are of concern, a calm algorithm should be incorporated. The original NTIS version should be replaced with Version 3 and additional updates undertaken as indicated above.

5.4.5 Updates Needed for Reactive-Pollutant Applications

Development and testing of algorithms to treat NO/NO_2 conversion in aircraft plumes should be undertaken (see, for example, Ref. 17). Development and testing of algorithms that can be used for treating more general reactive-pollutant problems, including photochemical-smog formation and visibility degradation, are needed. The above algorithms should be incorporated into a general computational package for either research or regulatory applications, as needed.

5.4.6 Revisions Needed to Enhance Usability

One approach to making AVAP more usable, especially to a broader spectrum of users, would be to redesign the computer code so that it could be installed on microcomputer or minicomputer systems. This would require that the emission and dispersion parts of the code be separated and that each part be further subdivided into stand-alone modules. Each module could be designed to read in data from the user terminal or from one or two external storage devices and to write data out onto one or two output data-storage devices that could be accessed by subsequent modules. An interactive data-file editor could be designed to further simplify the process of creating new data files or editing existing ones. Using the interactive mode for data-file operations and the batch mode for running computational codes could produce the optimum combination of ease of use and time saving.

A proposed new version of the AVAP model designed along the lines indicated above is discussed further in Sec. 9 of this report.

6 SUMMARY AND EVALUATION OF THE AQAM COMPUTER MODELS

6.1 THE AQAM

The AQAM is intended for use in evaluating the air-quality impacts of large military aviation facilities. As in the case of their civilian counterpart (AVAP), the AQAM computer codes are user-oriented codes with great flexibility. The user can elect to treat virtually any conceivable combination of aircraft, air-base, and environ sources likely to be encountered in or around an air base. Aircraft sources in particular can be treated in considerable detail — greater detail, in fact, than in the AVAP model. In contrast to its civilian counterpart, AQAM is composed of several stand-alone but compatible computer codes:

- Source-Emission-Inventory Model
- Short-Term Emission/Dispersion Model
- Long-Term Dispersion Model (Research Version and Applications Version)

The overall structure of the model is shown in Fig. 3. The dashed lines are used to distinguish the four separate component parts, which include the three separate computer codes listed above and a "Meteorological Data Program" that is operated on request by the Air Force Weather Service (ETAC).

The Short-Term Emission/Dispersion Model is used to calculate hourly average source-emission rates and pollutant concentrations. It utilizes essentially the same point-, area-, and line-source dispersion algorithms as the AVAP model. However, various updates and changes over the years have resulted in some minor differences in some of the algorithms.

The Long-Term Dispersion Model has no equivalent in the AVAP model. It employs a statistical-climatological-dispersion approach, as opposed to the hour-by-hour approach, to compute long-term average pollutant concentrations on a monthly or annual basis. Such averages can be computed for several distinct daily time intervals, as shown in Table 3. As indicated in Fig. 3, the Long-Term Dispersion Model requires meteorological input data prepared specifically for this purpose by ETAC.

There are two versions of the Long-Term Dispersion Model: the Research Version and an abridged version referred to as the Applications Version. The abridged version is somewhat less flexible but requires substantially less computer run time than the Research Version.

The Source-Emission-Inventory Model is also a physically separate computer code. It operates on user-input source data and produces a computer file, containing source information and annual average emission rates, that

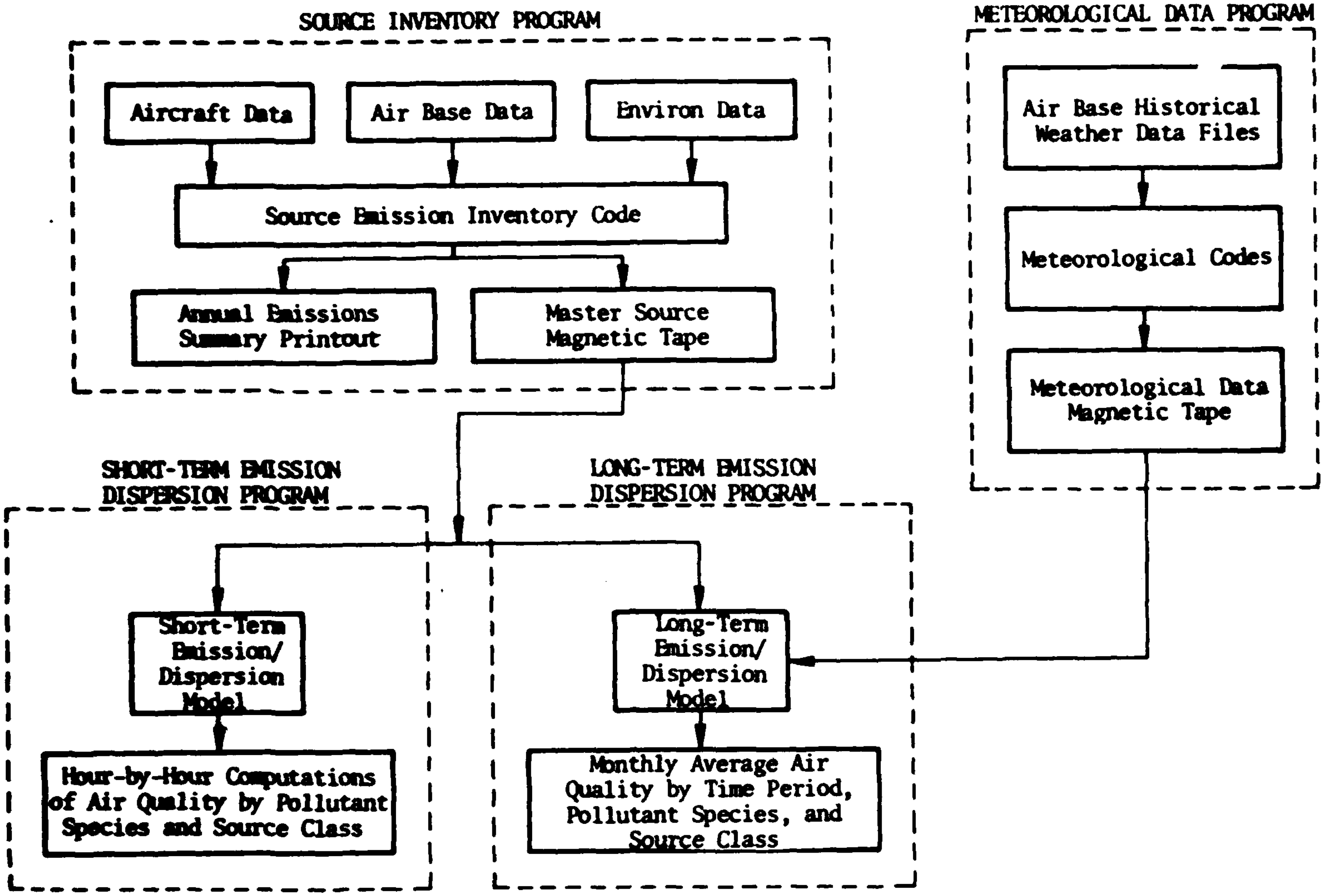


Fig. 3 Overall Structure of the Air Quality Assessment Model

Table 3 Definition of Diurnal Time Intervals Used in the AQAM Long-Term Dispersion Model

Period	Time Interval (LST)	Interpretation
1	0000 - 2400	all hours of day
2	0600 - 1800	business hours
3	0600 - 0900	morning rush hours
4	0900 - 1500	midday
5	1500 - 1800	evening rush hours
6	1800 - 2100	late evening
7	2100 - 0600	nighttime

can be used as an end product or as input to one of the AQAM dispersion models. The Source-Emission-Inventory Model organizes sources into aircraft, air-base nonaircraft, and environ source types, as does the AVAP model. It also defines point, line, and area source geometries. However, the structures of these two codes differ in accordance with operational differences at military and civilian facilities. Different aircraft types, operational modes, and engine thrust settings are defined in these codes, and the AQAM, in particular, places greater emphasis on aircraft-type-dependent operational parameters. Whereas runway, and therefore taxiway, assignments are based on aircraft range, wind direction, and airline in the AVAP model, they obey a different set of constraints at military facilities. The dependence of runway choice on wind direction, for example, is specified by the user in the form of a series of keys, that is, a sequence of ones and zeros, indicating whether the runway is used, for each of 16 wind-direction sectors. This is a simpler input scheme than the wind-quadrant procedure used in the AVAP model. Also, rather than specifying a taxiway-segment aircraft-activity matrix as in the AVAP model, AQAM employs taxiway trajectories, one for each runway-end and aircraft-parking-area combination. Each such trajectory may contain several straight-line taxiway segments. This scheme is better suited to military facilities and is very convenient for the input-data compiler but is not computationally optimal. In addition, military training flights and especially "touch-go" operations have no equivalent in commercial airports and therefore require special treatment in AQAM. Additional special military sources treated in AQAM include training fires and engine test-stand operations.

6.2 EXISTING VERSIONS OF AQAM

The original AQAM, as illustrated in Fig. 3, was described in detail in a technical document[18] dated February 1975. An operator's guide[19] was published in 1976, and detailed descriptions of the computer codes themselves, including flowcharts and subroutine descriptions, were published in three separate documents[20-22] in 1977. Between the time that the original technical documentation was drafted and the computer-code documentation was drafted, some changes were made in the codes. Because no attempt was made to update the original technical documentation, some inconsistencies exist between the computer-code and technical documentations.

After 1977, the Short-Term Emission/Dispersion and Source-Emission-Inventory codes were used primarily at Tyndall Air Force Base (AFB) for environmental impact studies, at Miramar Naval Air Base for studies of naval-aircraft impact and for validation studies, and at Argonne National Laboratory for validation and sensitivity studies and for development of refinements and improvements. Each of these groups made modifications to the original computer code to meet their missions, so there are now three separate versions of this model. No attempt will be made here to review the Navy version of the AQAM (see, for example, Ref. 23), but the other versions will be discussed in comparison with the original version in some detail below.

6.2.1 Current Version of AQAM in Use at Tyndall AFB (circa February 1982)

This version of the Short-Term Emission/Dispersion Model is essentially the same as that described in Ref. 20. However, line-by-line comparisons have revealed that some undocumented changes have been made in the Tyndall version. These include minor changes in the inputs and outputs, additions of some explanatory comments, and other minor coding changes of no consequence. One change that will affect the computations is the incorporation of a terrain-correction factor.

6.2.2 Validation-Study Version

Argonne National Laboratory prepared two slightly different versions of the AQAM computer code for purposes of performing calculations and comparing results with observations made at Williams AFB.[24,25] These versions, AQAM I and AQAM II, are briefly described in Refs. 24 and 25. AQAM I was set up to operate in precisely the same way that the original AQAM normally would be operated by a user. Namely, it accepts annual average emission data, which are subsequently reduced to hourly average emission rates using built-in algorithms that require as input various time-of-year, day-of-week, and time-of-day emission-distribution parameters. AQAM II, on the other hand, was set up to utilize observed hourly aircraft activity data taken at Williams AFB. With regard to the dispersion algorithms, AQAM I and AQAM II are identical. However, AQAM I and II are not identical to the version described in the original code documentation mentioned above. The differences are listed below:

- Different treatment of calm conditions.
- Different output structure.
- Use of a modified line-source dispersion algorithm, together with a more accurate "error function" subroutine.
- Other minor differences in coding.

The different treatment of calm conditions constitutes a major improvement in the Short-Term Emission/Dispersion Model. Unfortunately, documentation is presently limited to a technical description of the calm algorithm in draft form and a computer code listing. The use of a slightly modified line-source algorithm and a more accurate "error function" resulted in a substantial improvement in the accuracy of the code under certain rather special conditions but required only minor changes to the original computer code.

6.2.3 Other Changes

The only other major change of note has been the development of a completely new line-source algorithm. This algorithm has not been incorporated into any version of the Short-Term Emission/Dispersion Model as of yet, and it has not been formally published, although a technical description of the algorithm does exist in draft form and a code listing is available. This development results in a substantial improvement in the computer run time over that of the original algorithm, as well as a significant increase in accuracy. The increase in accuracy is only really significant for certain rather special combinations of input parameters that resulted in erroneous output from the original code.

6.3 COMPARISON OF THE VARIOUS VERSIONS OF THE SHORT-TERM AQAM

For purposes of this comparison, the three versions of the Short-Term AQAM shall be referred to as follows:

Version 1: Original documented version of the Short-Term Model

Version 2: Version used in the Williams AFB validation study

Version 3: Present Tyndall AFB version, February 16, 1982

6.3.1 Treatment of Low Wind Speeds

Versions 1 and 3 both assume that if the wind speed is less than 1 mph, the wind speed and direction are set to the nearest nonzero hourly value. Version 2 uses the calm algorithm.

6.3.2 Treatment of Lid Height or Mixing Depth

Versions 1 and 3 both require hourly values as input. Version 2 uses either the Nozaki equation (see Ref. 25, p. 60) or hourly input values from acoustic sounder data obtained at Williams AFB. If the wind is calm, Version 2 assumes pollutants are uniformly mixed in the vertical direction within the mixed layer.

6.3.3 Error Function

All three versions require the use of an error-function subroutine that is called by the line-source algorithm. Versions 1 and 3 use the same error-function subroutine. Version 3 uses a superior subroutine. In addition, there is also a minor change in the line-source algorithm itself in Version 2 that corrects an error that occurs only for certain combinations of input variables.

6.3.4 Terrain Correction Factor

Version 2 employs a terrain correction factor; the other two versions do not.

6.3.5 Plume Rise

Briggs's plume-rise formula has been added as an option to Version 3 but not to the other two.

6.3.6 Treatment of Large Area Sources

All three versions treat large area sources using the same algorithm. However, this algorithm is not documented in the technical report dated February 1975. It is an improved treatment compared with that described in the February 1975 document.

6.3.7 Input/Output Structure

There are some differences in the input/output statements appearing in the three codes. These differences do not affect the operation of the codes themselves.

6.4 AQAM EVALUATION

6.4.1 Intended Uses and Strengths

The AQAM package was originally designed for use on large, fast, main-frame computer facilities by environmental and computer staff at various Air Force installations. It was to be used to compute emissions and air quality on either a short-term or long-term basis. The models are very flexible and can be used for a wide variety of air-quality problems. Separate emission and dispersion computations can be performed. Considerable freedom of choice is available to the user regarding types of sources to be included in a particular calculation and the level of detail of treatment. At the time of development, the computer codes incorporated state-of-the-art emissions and dispersion modeling techniques for nonreactive pollutants (over time intervals of one hour) and for transport distances of the order of several kilometers away from the military installation. Provisions for treating a wide variety of aircraft, nonaircraft air-base, and environ sources were incorporated. The codes were designed to accept meteorological data routinely collected at air bases and processed by ETAC. The Long-Term Model, in particular, operates on a climatological joint stability and wind-rose data set prepared specifically by ETAC for that purpose. The original version of the AQAM computer codes is well documented, and the Short-Term Model, especially, has undergone extensive testing. Tests have included application to both the Washington National Airport[26] and Williams AFB[24,25] and extensive sensitivity analysis.[27] The Long-Term Model has been tested using hypothetical data bases only. Both the research and the applications versions of the Long-Term Model have been tested using hypothetical data bases and have been compared against each other and have undergone some sensitivity analyses.[28]

6.4.2 Limitations and Weaknesses

Model Usability

The generality and flexibility built into the original AQAM computer codes, along with the ability to treat aircraft operations at Air Force bases in great detail, has generated two problems that have limited the codes' use at various Air Force installations. First, the potential user tends to be put off by being confronted with having to proceed step-by-step through the user's guide, which requires him to make a large number of technical decisions and to gather, if the problem warrants it, a large body of information; this can be a very manpower-intensive process. Of course, if the scope of the problem is small, the input information requirements are correspondingly small. Nevertheless, even if the problem is a simple one, the novice user is still faced with what he may regard as an awesome task of becoming familiar with the general input structure and operation of the computer codes. The other problem is related to computer facility requirements. If the number of sources, especially line sources, used in the problem is large, then the computer run time, especially on older facilities, can be excessively long. Furthermore, regardless of the scope of the problem, the computer core-storage requirement is large and, in fact, often too large for the many computer installations at which severe constraints are placed on users for one reason or another.

Documentation

Although the original AQAM has been fully documented, a number of code changes and updates have been implemented by Air Force personnel in the Tyndall version and by Argonne staff in the version used in the Williams AFB Validation Study. These changes, especially those implemented at Argonne, *affect model performance under certain conditions.* The published documentation has not been correspondingly updated.

Technical Issues

The technical limitations and weaknesses of the AQAM dispersion codes are essentially the same as those of the AVAP computer codes (see Sec. 5.4.2) with the following exceptions:

- The AQAM codes have not been updated to include the results of the Dulles and Washington National airport experiments regarding jet-aircraft plume rise and initial dispersion.

- The AQAM Short-Term Model (the version used in the Williams AFB Validation Study) contains a calm algorithm, whereas the AVAP model does not. AQAM also contains a superior "error function" subroutine that eliminates some of the numerical problems arising from certain combinations of inputs to the AVAP code.

- *The Williams AFB Validation Study* version also contains the default option of using the Nosaki equation to compute mixing depth. However, this equation has been shown to be inadequate. A better default option is required. The default algorithm used in the AVAP model, although not adequate either, is probably superior to the Nozaki equation.

- The level of treatment of aircraft and air-base sources available to the user in the AQAM is probably unnecessarily detailed. For most purposes, the number of source types could be reduced and the use of aircraft-dependent operational parameters could be replaced with the use of generic operational parameters.

6.4.3 Updates Essential for Inert-Pollutant and/or Screening Applications

See Sec. 5.4.3.

6.4.4 Additional Updates Desirable for Inert-Pollutants and/or Screening Applications

See Sec. 5.4.4. In addition, the documentation should be updated, and minor differences among existing versions of the AQAM should be eliminated.

6.4.5 Updates Needed for Reactive-Pollutant Modeling

See Sec. 5.4.5.

6.4.6 Revisions Needed to Enhance Usability

As with the AVAP computer code, the best way to improve the usability of the AQAM codes, especially to make it useful to a broader spectrum of users, is to redesign the codes so that they can be operated on microcomputer or minicomputer systems. Although the emission and dispersion computer codes for the Short-Term Model are already separated, the separation is incomplete. For example, emission rates dependent on the specific hour of simulation or on the associated meteorology for that hour are still computed within the short-term emission/dispersion computer program. Furthermore, and even more important, the structure of the AQAM codes and the size of the arrays used to store input data preclude the use of computers having only modest core storage. Hence, a course of action similar to that briefly outlined in Sec. 5.4.6 for the AVAP model could be taken for the AQAM as well. Proposed new designs for both the AVAP model and AQAM are discussed in Sec. 9.

7 MODEL COMPARISONS AND RECOMMENDATIONS

Although the AVAP model and AQAM started off having virtually the same dispersion algorithms, these algorithms have evolved along somewhat separate paths due to various updates and refinements. The purpose of the present comparison is to point out the similarities and differences and to select, where possible, the best that each model has to offer. These "best" offerings could then be used to guide the development of a new composite or joint military/civilian dispersion package. For some features of the dispersion problem, neither model treatment may be completely satisfactory. In such cases, other alternatives are suggested.

For the purposes of this comparison, the version of the AVAP model used in the Updated Assessment of Air Quality Impacts at Major U.S. Airports[24,25] and the version of the AQAM used in the Williams AFB Validation Study (AQAM I is technically equivalent to AQAM II) will be used.

Table 4 summarizes the methods used by each of these two models to treat each feature of the modeling problem. Recommendations for the "best" method of treating each feature are also given in the table.

Table 4 Comparison of the AQAM and AVAP Models

Feature	AVAP[a]	AQAM[b]	Recommendation
Emission/dispersion codes	Combined.	Separated (partially).	Separate emission from dispersion codes. Make dispersion codes common to both civilian and military models.
User mode	Batch.	Batch (SIIIM-Interactive Editor used to modify emission inventory) (see Ref. 29).	Develop interactive data-file editing programs and batch-mode emission computational programs for both AVAP and AQAM. Simplify and remove or make optional unnecessary sources.
Pollutant concentration averaging time	Short-Term Model: hourly averages.	Short-Term Model: hourly averages. Long-Term Model: monthly or annual averages by time of day.	Keep hourly averages for Short-Term Model. Limit Long-Term Model to annual averages and use Applications Version of AQAM for military applications. If long-term model needed for civilian use, adapt long-term version of AQAM.
Emission-averaging period	Hourly -- on the basis of hourly activity.	Annual emissions based on annual activity. Hourly emissions or other-time-interval emissions are computed from distribution factors applied to annual average activity levels.	Procedures satisfactory for present versions of AVAP and AQAM. However, if new versions are made for smaller computers, then hourly averages should be computed on the basis of hourly activity for both AVAP and AQAM. If desired, annual averages should be estimated only for emission accounting purposes using LTO cycle-type emission factors.
Source geometries	Points, lines, areas. Arbitrary length and orientation of lines.	Same as AVAP.	No changes.
Source types	Aircraft, nonaircraft airport, and environ. Each type may have point, line, or area source geometries.	Same three general types. Specific sources may differ.	Eliminate environ sources. Eliminate, or treat as separate problem, special sources that do not operate continuously (training fires, engine test-stand operations, etc.).
A/C[c] engine operational modes or thrust settings	Approach, landing (mixed mode), taxi/idle, takeoff, and climbout.	Intermediate, landing (mixed mode), military, and afterburner.	Keep as is for now. Evaluate need for alterations in taxi mode.
A/C operational modes	Idle in gate area. Taxi in gate area. Outbound taxi. Idle in runway queue. Takeoff roll. Climbout (one path per runway, path may consist of up to two straight-line segments of equal angle of elevation but different azimuths). Approach (one path per runway consisting of one straight-line segment). Inbound taxi. Idle in gate area. Auxiliary power unit (APU) operation in gate area.	Idle at startup. Outbound taxi. Engine check. Runway roll. Climbout 1 and 2 (A/C-type-dependent trajectories). Approach 1 and 2 (A/C-type-dependent trajectories). Landing. Inbound taxi. Idle at shutdown. For training flights: "touch-go" operations.	Eliminate A/C-type-dependent airborne trajectories in AQAM. Make all airborne operations optional, especially for dispersion calculations. Use only one approach path (with up to two segments) per runway. Use only one departure path (with up to two segments) per runway.

Table 4 (Cont'd)

Feature	AVAP[a]	AQAM[b]	Recommendation
Method of computing A/C emissions per A/C type	Number of engines × engine emission factor for a given thrust setting.	Same as AVAP.	Store emission factors per A/C type rather than per engine type.
Documentation	Original version of AVAP: technical documentation and user's guide available from FAA and NTIS. Abbreviated version: user's guide available only in draft form. Updated AVAP: technical documentation available from FAA; no updated user's guide.	Tyndall Version of AQAM: very similar to original AQAM, which is documented in computer code documents and a user's guide. Technical report is somewhat outdated. Argonne's version used in Williams AFB Validation Study: only partially described in USAF technical report.	Update AVAP and AQAM documentation but not before implementing some additional code changes designed to reduce computer run time, reduce core storage, and improve accuracy.
Code availability	Original version of AVAP: available from NTIS. Abbreviated version and updated version: available from FAA.	Tyndall Version available from Tyndall AFB. Version used in Williams AFB Validation Study not readily available to public.	Replace NTIS version of AVAP with updated version after all desirable changes have been made.
Point-source plume-rise formulas	User's choice of Holland or Carson and Moses.	User's choice of Holland, Carson and Moses, or Briggs.	Retain AQAM choices.
Building and stack downwash and wake effects	Briggs's "Rules of Thumb" and enhanced initial plume dispersion.	Same as AVAP.	Update in accordance with state-of-the-art advances.
A/C plume rise and initial values of dispersion parameters	Based on Bullee 3-Tower Experiment for taxiing mode. Initial dispersion for takeoff based on DCA experiments. No plume rise in takeoff.	No plume rise. Original values for σ_{yo} and σ_{zo} have not been updated.	Use AVAP values for taxi/idle modes. Perform further analysis of O'Hare and DCA data to get values for takeoff and runway queues. Additional field data would be desirable. In interim, use AVAP.
Treatment of initial dispersion parameters (σ_{yo}, σ_{zo})	For non-A/C and environ sources. Uses virtual-point-source method, numerically solve for x_o in $\sigma_{y,z}(x_o) = \sigma_{yo,zo}$, then use $\sigma_{y,z} = \sigma_{y,z}(x + x_o)$. For A/C line sources uses summation of variance.	Uses virtual-point-source method for all sources. However, uses analytical rather than numerical solution of equation shown under AVAP (much faster).	Use summation-of-variance procedure for all sources. This procedure is technically preferred and uses less computer time.
A/C-engine emission factors	Updated to 1977 EPA-published values.	Updated to 1978 USAF-published values (in Tyndall Version).	Update as newer information becomes available.

Table 4 (Cont'd)

Feature	AVAP[a]	AQAM[b]	Recommendation
A/C departure queue	Departure queue length based on calculations using empirical algorithm. Observed time in queue in recent field programs agrees with algorithm in original AVAP model.	None considered.	Use AVAP or similar algorithm. Test against available data. Queuing effects found to have large impact on emission distribution.
A/C taxi speed	A/C-range dependent and dependent on whether gate area, inbound, or outbound. Adjustment factors can be entered to increase or decrease speed on each taxiway segment to simulate congestion.	A/C-type dependent. Same speed for all taxiway segments. No capability to simulate congestion.	AVAP procedure is best because it yields more realistic emission distributions.
A/C time-in-mode	Input by user. Recommended values based on recent observations at LAX, JFK, ORD. (Recent values ≠ original values given in NTIS document.)	Input by user. Default values are circa 1975.	Retain user input and alter defaults as more recent data become available.
A/C hourly activity	User enters hourly arrivals and departures.	User enters annual average diurnal pattern and selects factors to allocate activity to particular time of year or hour.	Leave as is for current versions of AVAP and AQAM. If new versions are designed, use user-entered hourly activity values.
Atmospheric stability classification scheme	Pasquill, Gifford, Turner scheme based only on surface weather observations.	Same as AVAP.	Investigate use of revised procedure based on recent recommendations of AMS. Determine if the procedure is superior and what additional input data are required.
Depth of the mixed layer	User enters hourly value. Default: Holzworth's climatological value for each region.	User enters hourly value. Default: Nozaki equation.	Neither default is adequate. Nozaki equation compares very poorly with measurements. Develop alternative.
Determination of critical downwind distance for uniform vertical mixing	Uses numerical procedure similar to that used to find pseudo-upwind distance to a virtual point source.	Evaluates an analytical expression.	AQAM procedure is much faster. Should be used for AVAP as well.

Table 4 (Cont'd)

Feature	AVAP[a]	AQAM[b]	Recommendation
Horizontal dispersion parameters and effect of meandering wind direction at low wind speed	At moderate-to-high wind speed, σ_y taken from PGT curves with correction for 1-hr sampling time. For low wind speeds, σ_y taken from Turner's Nashville study and corrected for 1-hr sampling time. These latter curves are for urban conditions and are similar to those obtained by McElroy and Pooler in St. Louis. They are expressed in terms of travel time.	Same as AVAP.	Investigate simplification and alternative procedure for computing to reduce computer run time.
Vertical dispersion parameters	σ_z curves from same sources as σ_y. Adjusted for sampling times over 20 min. Also adjusted for enhancement due to plume rise following suggestion of Pasquill, which is consistent with results of Dulles Tower Experiments.	Same as AVAP except no adjustment for enhancement due to plume rise. Note: Tyndall Version has an error in the inverse expression used to evaluate x_z, given σ_z.	Investigate simplification and alternative procedure for computing to reduce computer run time. Also adjust to sampling times >10 min only.
Wind-speed profile	Exponential wind-speed profile with exponent based on PGT stability class.	Same as AVAP.	No change.
Low-wind-speed treatment	Assume wind speed and wind direction of nearest noncalm period prevails.	Special calm algorithm that accounts for dispersion during calm period and advection of calm cloud after winds pick up again. Uses dispersion coefficients based on theoretical and experimental study of dispersion under light wind conditions.	Use AVAP, provided calm conditions are not important. If they are important, use AQAM approach.
Line-source algorithm	Algorithm handles straight lines of arbitrary length and orientation. Divides line into short segments and uses analytical expression involving error functions. Uses updated versions of error function and difference of error functions subroutines. Some problems under certain unusual combinations of input values. Most time-consuming part of computer code.	Same as AVAP.	Replace with recently developed numerical-integration scheme that has been shown to be more accurate and much faster.

Table 4 (Cont'd)

Feature	AVAP[a]	AOAM[b]	Recommendation
Area-source algorithm	If small, treat as point source with appropriate values of σ_{yo} and σ_{zo} (using upwind virtual-point-source method). If large, use algorithm based on approximate analytical integration of 2-D integral. Treats lid effects.	Same as AVAP.	Okay as is. If greater accuracy desired, go to numerical integration scheme.
Terrain	No adjustment.	No adjustment. Note: Tyndall Version has an adjustment factor.	Investigate use of adjustment factor as in Tyndall Version. If satisfactory, add to AVAP.
Output	Prints out input data in table and prints results of concentration calculations on a receptor grid. Indicates contributions from several source types separately. Output can be stored for further use or contour plotting. $1/r^p$ used for interpolation between grid points for contour plotting.	Prints input and output data similar to AVAP. No special provision for contour plotting. Output can be stored for further analysis. Special statistics package available for analysis of output data.	No changes at this time.

[a] Version used in Updated Assessment of Air Quality Impacts at Major U.S. Airports.[11-13]

[b] Version used in Williams AFB Validation Study.[24,25]

[c] A/C = aircraft.

8 WHICH DIRECTION SHOULD FUTURE EFFORTS TAKE? -- A DECISION TREE

A combination of changing operational and technical requirements for models and computer codes; advances in the state of the art of modeling; availability of modern, low-cost microcomputers and minicomputers; and numerous inconsistencies between various currently in-use versions of AVAP and AQAM computer codes and documentation raises a number of interrelated questions regarding where future efforts should be headed.

For example, should research and development (R&D) tasks be undertaken to advance the state of the art of emission and/or dispersion modeling or should future efforts be directed more toward applications issues and, in particular, toward improvement of model usability?

Should the inconsistencies that have been pointed out between various computer codes and their documentation be resolved now or should such updating be postponed until already-developed, superior algorithms are incorporated into the codes? Alternatively, should the AQAM and AVAP packages continue to be supported as separate systems or should a joint package that takes advantage of the best elements of both systems be developed? Should that joint package incorporate all of the latest algorithms? Should further efforts to improve or update the current large models be suspended in favor of designing new versions specifically for modern microcomputers and/or minicomputers?

These issues and others point to the need for a systematic decision-making procedure. One approach to such a systematic procedure is to formulate a "decision tree" that reveals the various options and their consequences. Figure 4 shows a first attempt at a decision tree developed for the purpose of sorting out some of the options for proceeding with the AVAP model and AQAM. No attempt is made to display all of the possible options or to even fully characterize the options that are given. Rather, this decision tree should be regarded simply as a guide to future decision making. Alternative branches can be readily added and further expanded.

The decision tree contains question marks that are located at branch points or decision points. The straight lines radiating from each question mark indicate the alternative paths that various decisions will lead to. For example, on the first diagram, the first question mark requiring a decision refers to the question of whether to support applications or R&D-related work. The line going to the left shows the "applications branch." Following along the "applications branch," the next decision concerns the choice between "user" and "specialist" models. Following the "user branch," the next decision concerns the choice between separate AVAP and AQAM packages and a Joint Air Quality Modeling Package (JAQMP), etc. The circled letters, which appear at the lower extremities of each of the branches, refer to continuations that are shown on subsequent pages.

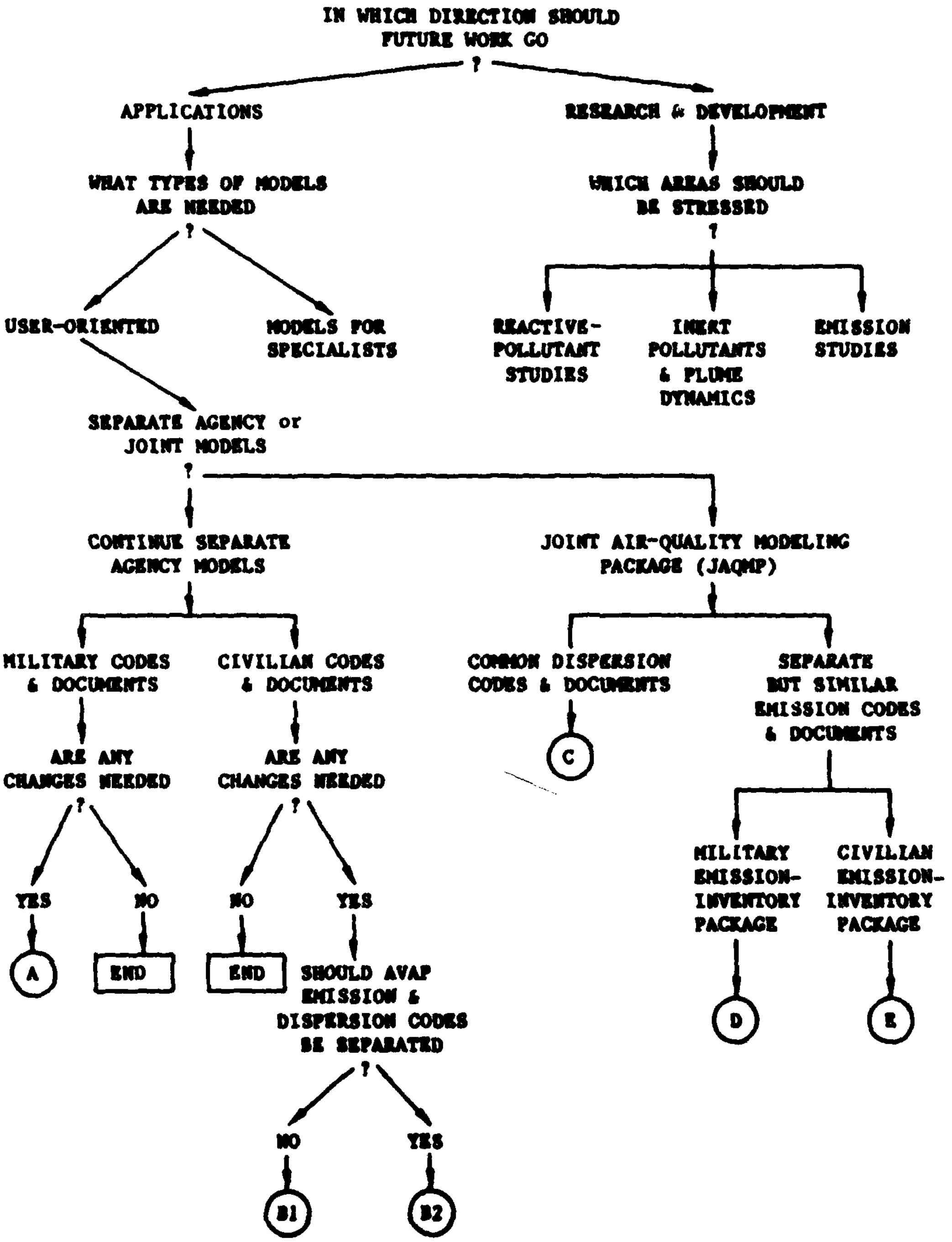


Fig. 4 A Decision Tree for Emission and Air-Quality Modeling for Aviation Applications

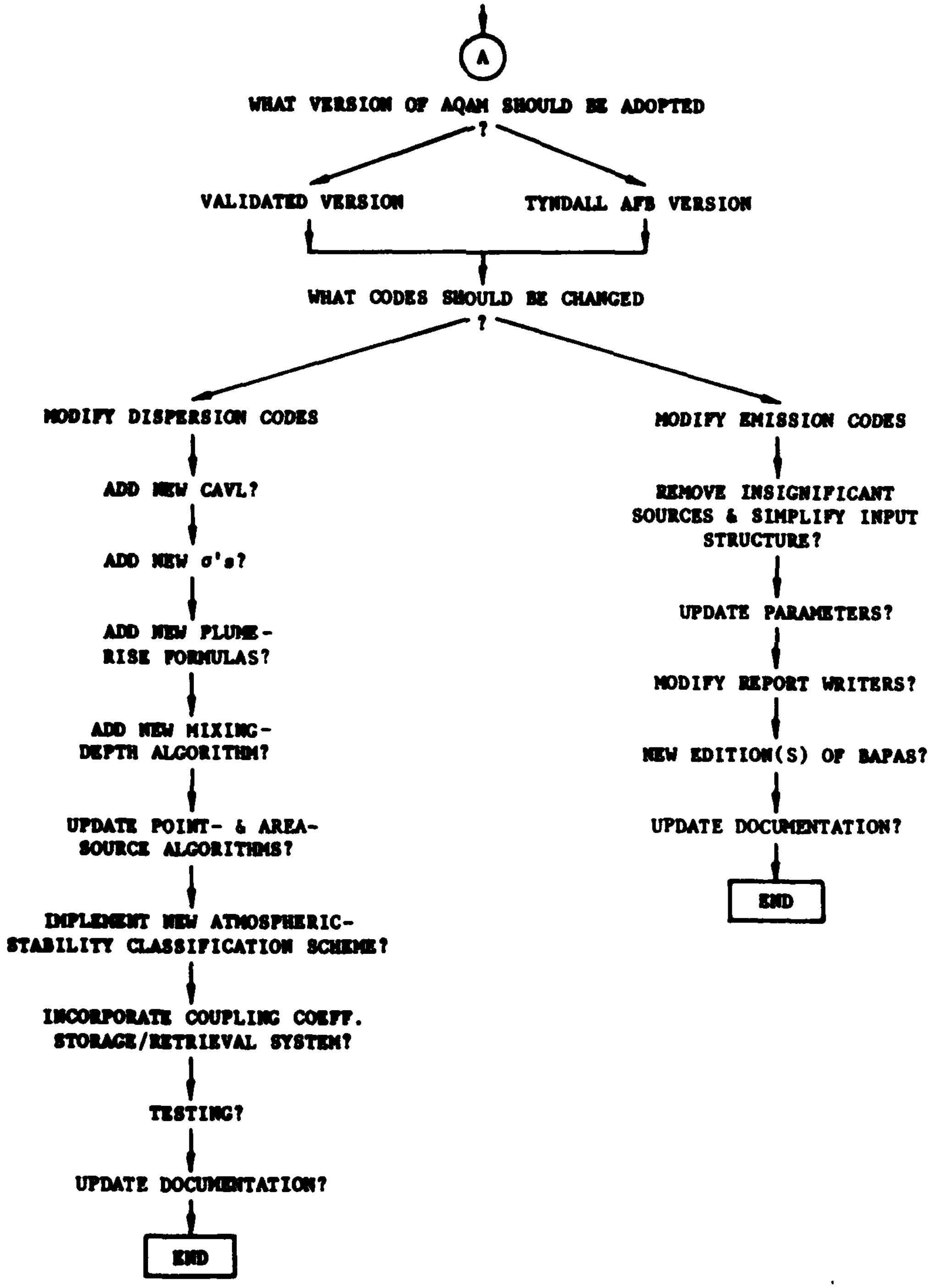

A
WHAT VERSION OF AQAM SHOULD BE ADOPTED ?
VALIDATED VERSION
TYNDALL AFB VERSION
WHAT CODES SHOULD BE CHANGED ?
MODIFY DISPERSION CODES
ADD NEW CAVL?
ADD NEW σ's?
ADD NEW PLUME-RISE FORMULAS?
ADD NEW MIXING-DEPTH ALGORITHM?
UPDATE POINT- & AREA-SOURCE ALGORITHMS?
IMPLEMENT NEW ATMOSPHERIC-STABILITY CLASSIFICATION SCHEME?
INCORPORATE COUPLING COEFF. STORAGE/RETRIEVAL SYSTEM?
TESTING?
UPDATE DOCUMENTATION?
END
MODIFY EMISSION CODES
REMOVE INSIGNIFICANT SOURCES & SIMPLIFY INPUT STRUCTURE?
UPDATE PARAMETERS?
MODIFY REPORT WRITERS?
NEW EDITION(S) OF BAPAS?
UPDATE DOCUMENTATION?
END

Fig. 4 (Cont'd)

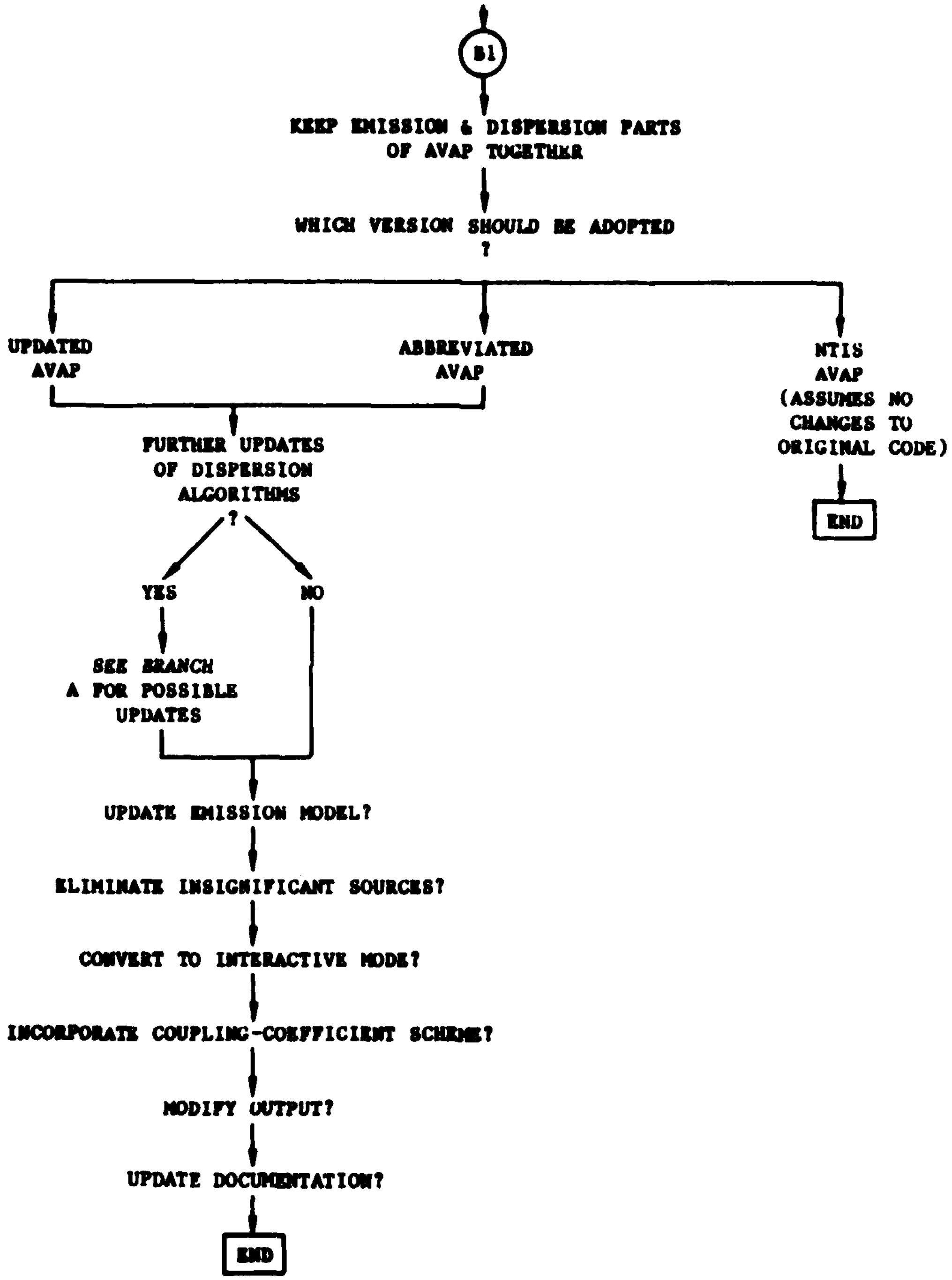

B1
KEEP EMISSION & DISPERSION PARTS OF AVAP TOGETHER
WHICH VERSION SHOULD BE ADOPTED ?
UPDATED AVAP
ABBREVIATED AVAP
NTIS AVAP (ASSUMES NO CHANGES TO ORIGINAL CODE)
END
FURTHER UPDATES OF DISPERSION ALGORITHMS ?
YES
NO
SEE BRANCH A FOR POSSIBLE UPDATES
UPDATE EMISSION MODEL?
ELIMINATE INSIGNIFICANT SOURCES?
CONVERT TO INTERACTIVE MODE?
INCORPORATE COUPLING-COEFFICIENT SCHEME?
MODIFY OUTPUT?
UPDATE DOCUMENTATION?
END

Fig. 4 (Cont'd)

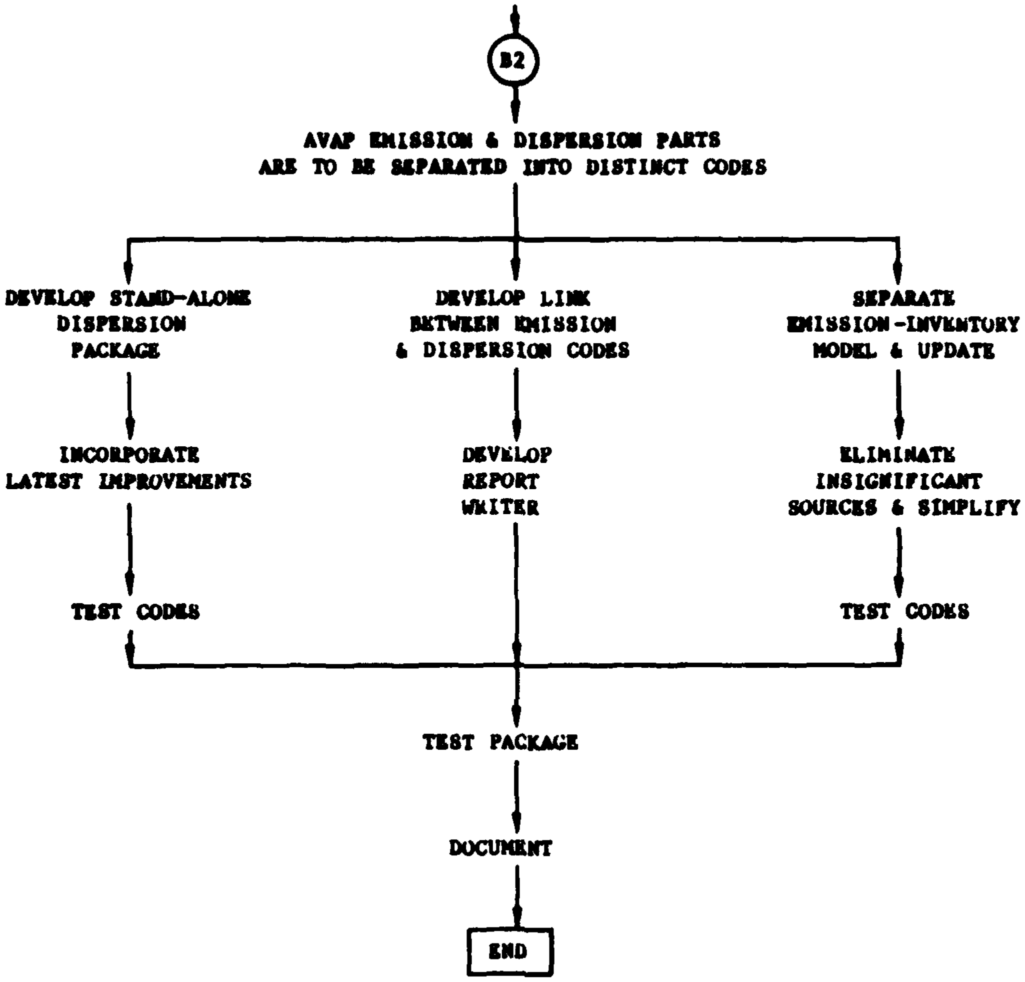
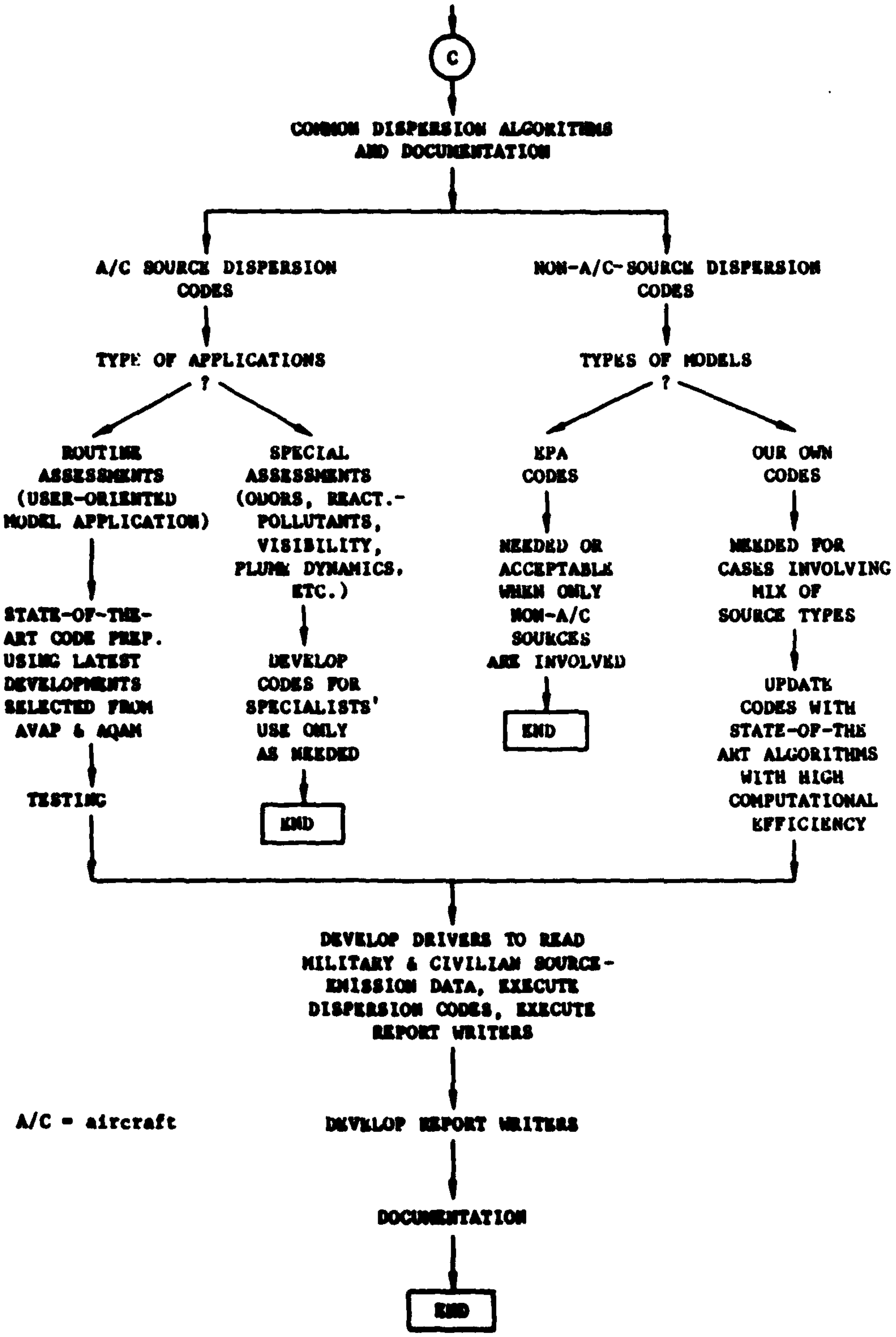

B2
AVAP EMISSION & DISPERSION PARTS
ARE TO BE SEPARATED INTO DISTINCT CODES
DEVELOP STAND-ALONE
DISPERSION
PACKAGE
DEVELOP LINK
BETWEEN EMISSION
& DISPERSION CODES
SEPARATE
EMISSION-INVENTORY
MODEL & UPDATE
INCORPORATE
LATEST IMPROVEMENTS
DEVELOP
REPORT
WRITER
ELIMINATE
INSIGNIFICANT
SOURCES & SIMPLIFY
TEST CODES
TEST CODES
TEST PACKAGE
DOCUMENT
END

Fig. 4 (Cont'd)



A/C = aircraft

Fig. 4 (Cont'd)

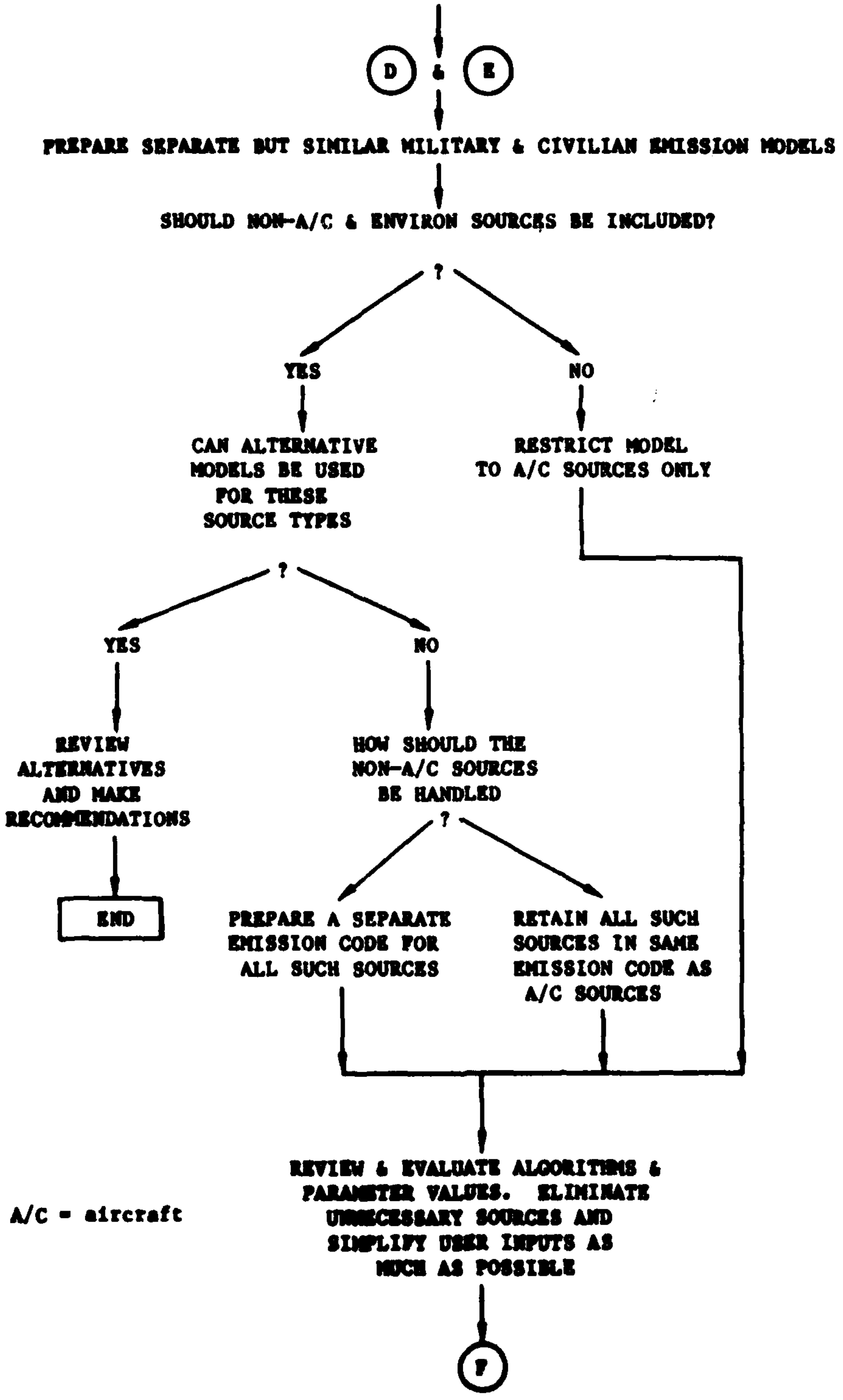

D
&
E
PREPARE SEPARATE BUT SIMILAR MILITARY & CIVILIAN EMISSION MODELS
SHOULD NON-A/C & ENVIRON SOURCES BE INCLUDED?
?
YES
NO
CAN ALTERNATIVE MODELS BE USED FOR THESE SOURCE TYPES
RESTRICT MODEL TO A/C SOURCES ONLY
?
YES
NO
REVIEW ALTERNATIVES AND MAKE RECOMMENDATIONS
HOW SHOULD THE NON-A/C SOURCES BE HANDLED
?
END
PREPARE A SEPARATE EMISSION CODE FOR ALL SUCH SOURCES
RETAIN ALL SUCH SOURCES IN SAME EMISSION CODE AS A/C SOURCES
REVIEW & EVALUATE ALGORITHMS & PARAMETER VALUES. ELIMINATE UNNECESSARY SOURCES AND SIMPLIFY USER INPUTS AS MUCH AS POSSIBLE
A/C = aircraft
F

Fig. 4 (Cont'd)

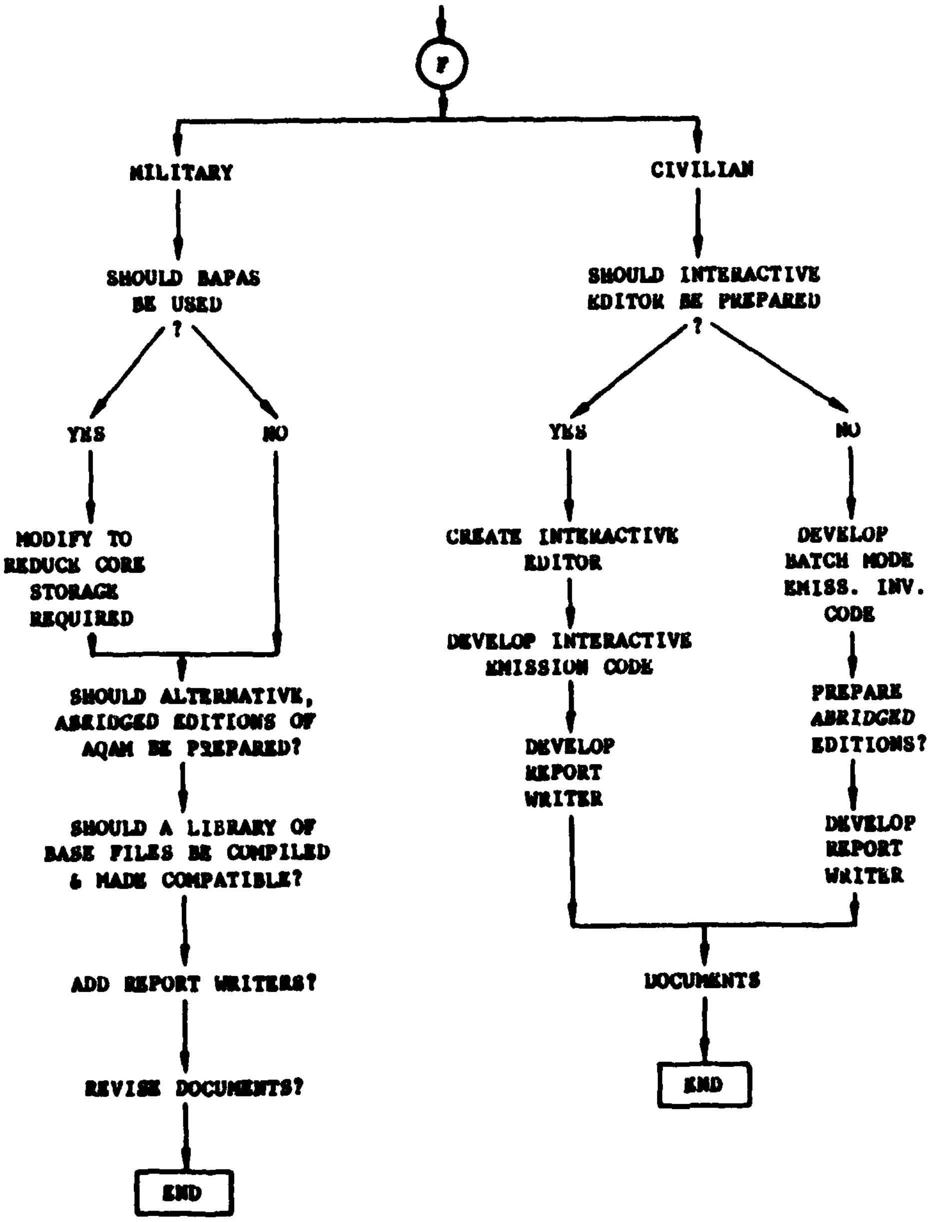

F
MILITARY
CIVILIAN
SHOULD BAPAS BE USED ?
SHOULD INTERACTIVE EDITOR BE PREPARED ?
YES
NO
YES
NO
MODIFY TO REDUCE CORE STORAGE REQUIRED
CREATE INTERACTIVE EDITOR
DEVELOP BATCH MODE EMISS. INV. CODE
DEVELOP INTERACTIVE EMISSION CODE
SHOULD ALTERNATIVE, ABRIDGED EDITIONS OF AQAM BE PREPARED?
PREPARE *ABRIDGED* EDITIONS?
DEVELOP REPORT WRITER
DEVELOP REPORT WRITER
SHOULD A LIBRARY OF BASE FILES BE COMPILED & MADE COMPATIBLE?
DOCUMENTS
ADD REPORT WRITERS?
END
REVISE DOCUMENTS?
END

Fig. 4 (Cont'd)

9 OUTLINE OF A PROPOSED NEW DESIGN FOR THE AVAP AND AQAM EMISSION MODELS

A new computational system consisting of a set of stand-alone computer programs is being recommended for use in cases in which the scope of the problem does not warrant, or available computer facilities do not permit, the use of the full AVAP model or AQAM. To date, only the emission portion, or "front end," of the system has been considered in any detail.

A descriptive outline of the system is presented in this section, together with some macro flowcharts illustrating its overall structure and major components. This section also contains some discussion of the rationale leading to the design choices embodied in the new system. Detailed flowcharts and descriptions of data-file structures and contents are contained in Ref. 30.

The overall structure of the civilian and military versions of the new system is sufficiently similar that only a single, generic system needs to be described. When necessary, distinguishing features applicable only to the military or civilian versions will be noted.

The new computational system is designed in a modular fashion to accommodate small computers, while at the same time providing the user with the flexibility to treat a variety of source types and configurations and to perform either emissions or pollutant-concentration calculations. Each module or subprogram is designed to read, at most, one or two input data files and write, at most, one or two output data files. New files can be created from scratch or old data files can be edited as required. For a given type of problem, only those subprograms and corresponding data files that are required are actually used. This saves a considerable amount of core storage as compared with the full AVAP or AQAM computer codes.

The emission and dispersion portions of the system are completely separated from each other, eliminating the need to provide core storage for both when only one portion may actually be required. In the AVAP model, both portions are combined into a single code. In AQAM, the source emission inventory is compiled and annual average emission rates are computed in the Source-Emission-Inventory Model computer code. The remaining short-term emission and dispersion model calculations are performed in the Short-Term Emission/ Dispersion Model computer code. Figure 5 illustrates the AQAM Short-Term Model computer-code structure. All of the subroutines contained within the dotted line are associated with the computation of short-term emission rates. These subroutines or their equivalents would be placed in separate modules in the new computational system. Furthermore, whereas it is now necessary to place the entire emission inventory into core to compute the pollutant-concentration contribution from each source, in the new system only one source will occupy the core at a time! This will result in a very substantial reduction in core-storage requirements.

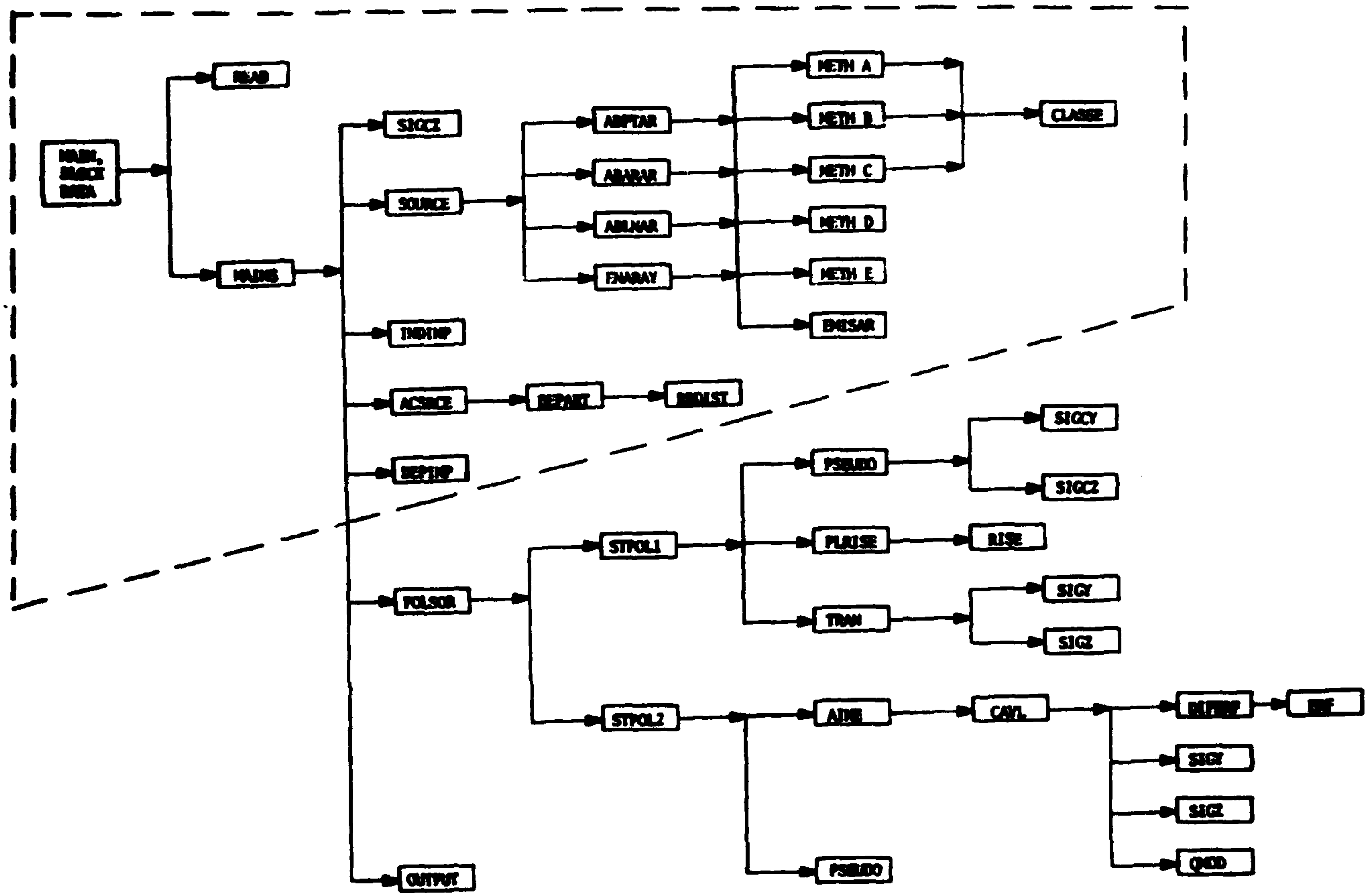


Fig. 5 Short-Term Emission/Dispersion AQAM (dashed line encloses all of the emission computation subroutines)

For user convenience, a special module is proposed that will create or edit the basic input data files. It will be operable in the interactive mode, while the main computational routines will be operable in the batch mode. This mixed-mode system will simplify the user's task of compiling the input data files, while avoiding the necessity of long sessions at the computer terminal during the longer run times required by the computational programs.

9.1 OVERALL STRUCTURE OF THE NEW SYSTEM

An overview of the new computational system is shown in Fig. 6. Note that the user is expected to have access to a microcomputer or minicomputer system that utilizes at least two permanent storage devices (e.g., disk readers/writers). This hardware requirement is necessary for the efficient interactive processing of input and output data files. Once these files have been prepared, they are subsequently used by the computational computer routines to generate either emission rates or ambient concentrations. It is desirable, but not essential, to have access to a mainframe computer for doing the batch mode emission and dispersion calculations. (Microcomputers or minicomputers may be used if the number of sources to be analyzed is small.)

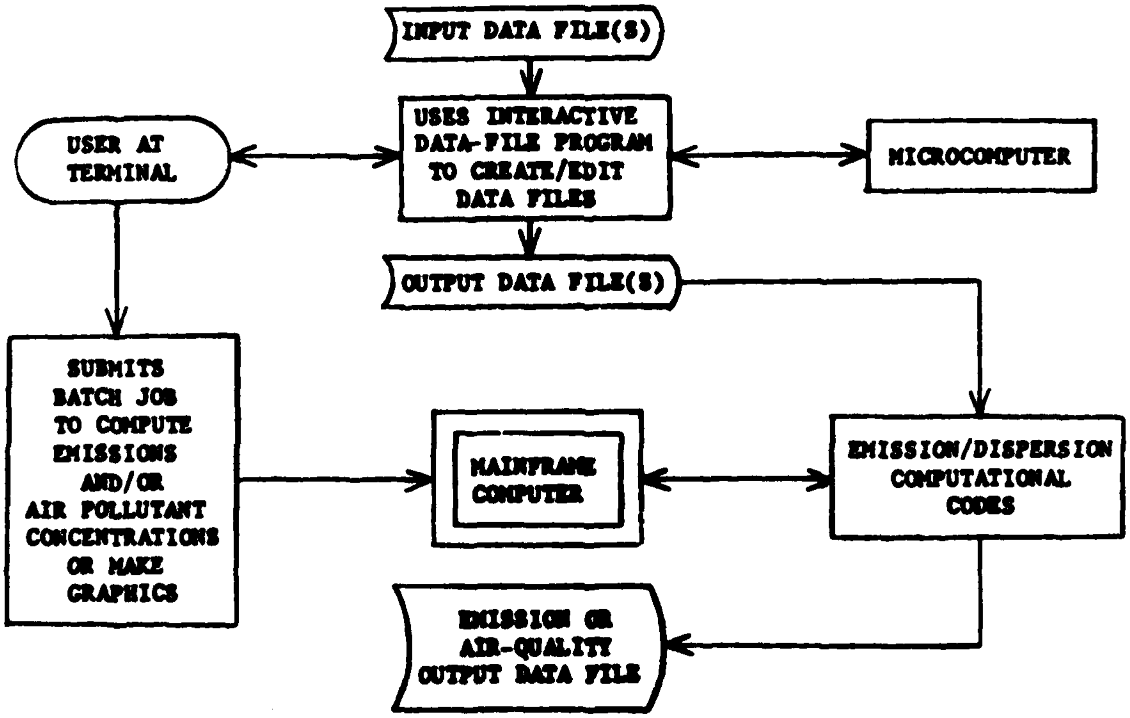


Fig. 6 Interactive and Batch-Mode Computer Operations -- An Overview of the Computational System

Figures 7a and 7b show macro flowcharts of the short-term (hourly) emissions and dispersion portions of the system, respectively. In both charts the major processing steps are shown to the left in rectangular boxes, with the processing sequence proceeding downward as indicated by the arrows. The boxes and arrows shown on a particular horizontal line represent the input of data from data files and the processing of data to create or edit the data files needed to carry out the major steps shown to the left. Note that the various data files are identified by numbers for convenience.

Each of the data-processing steps along a horizontal line or the major steps in the vertical line can be performed as separate, isolated computer operations or clustered together as dictated by the optimal use of the user's computational facilities. For example, beginning on the first line of the first chart, the user may elect to input data via the Interactive Data-File Program (I.D.F.P.) and create File 1 in a single operation. He may then create File 2 in another step. Then he can exercise the aircraft-source-emissions code that requires File 1 and File 2 as inputs and that generates File 7 as an output in a single batch-mode operation.

Note that at the end of the second chart, the user is given several output options. In general, the user should be given the choice of outputting individual or accumulated source contributions to pollutant concentrations at each receptor.

9.2 LONG-TERM EMISSION ESTIMATES

The macro flowcharts shown in Figs. 7a and 7b illustrate only the short-term (hourly) emission and dispersion calculations. In addition, it may be desirable, for emission-reporting purposes, to also compute annual average emissions.* In some cases, only annual average emissions may be required. For the sake of computational efficiency, it is worthwhile to have separate computer programs for estimating hourly and annual average emissions. Note that simply scaling hourly emissions up or annual emissions down may not be satisfactory, since the hourly average emission rates of interest may not be typical for the entire year.

Figure 8 illustrates a straightforward procedure for structuring an annual-average-emission computation routine. Note that such a routine requires the use of LTO-cycle-type emission factors.

9.3 DATA FILES AND THE INTERACTIVE DATA-FILE PROGRAM

The new computational system makes extensive use of data files. These files are the means by which one module, representing one step in the

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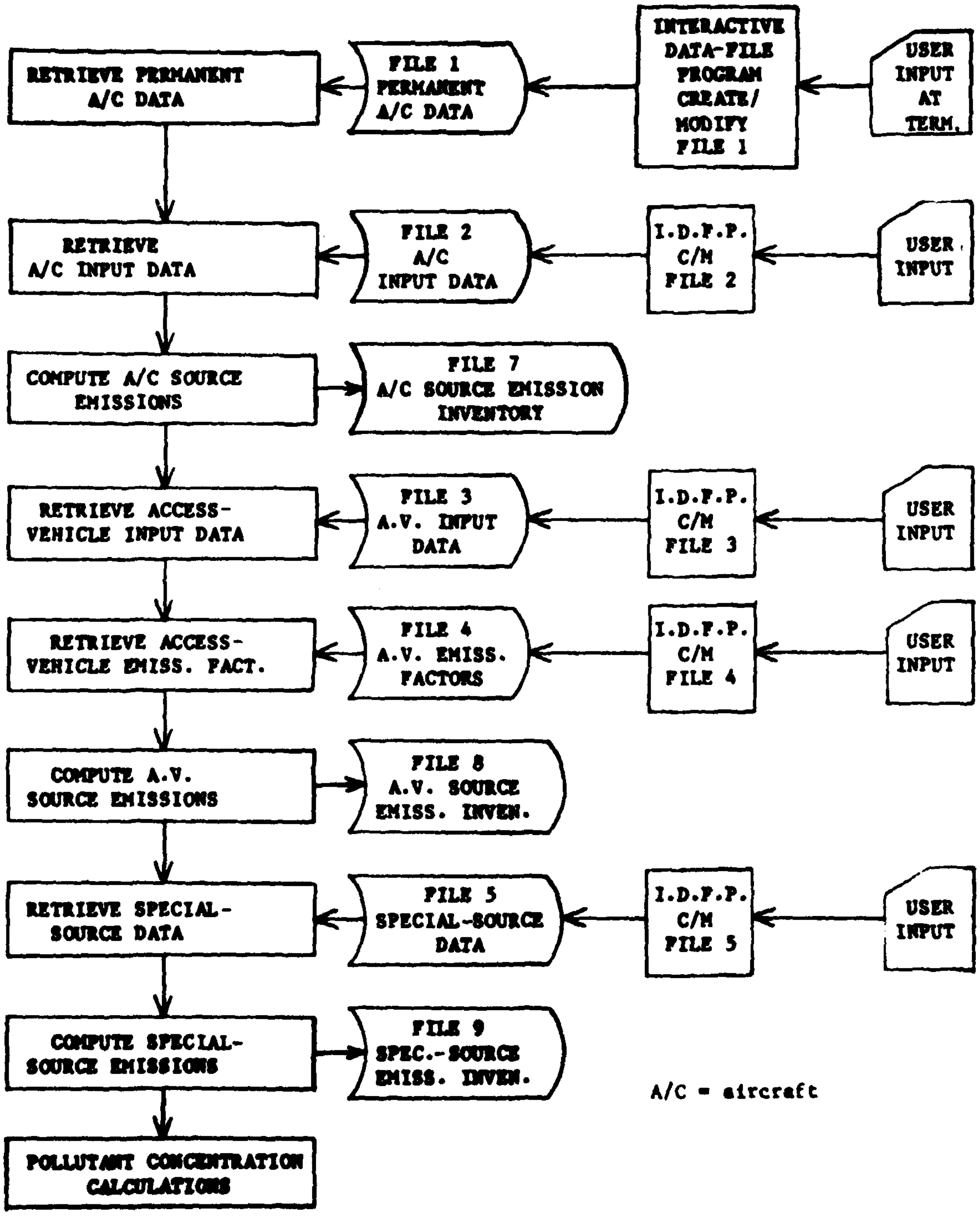
*This has been a traditional requirement for military purposes.



A/C = aircraft

Fig. 7a Macro Flowchart of Short-Term Emission Computations

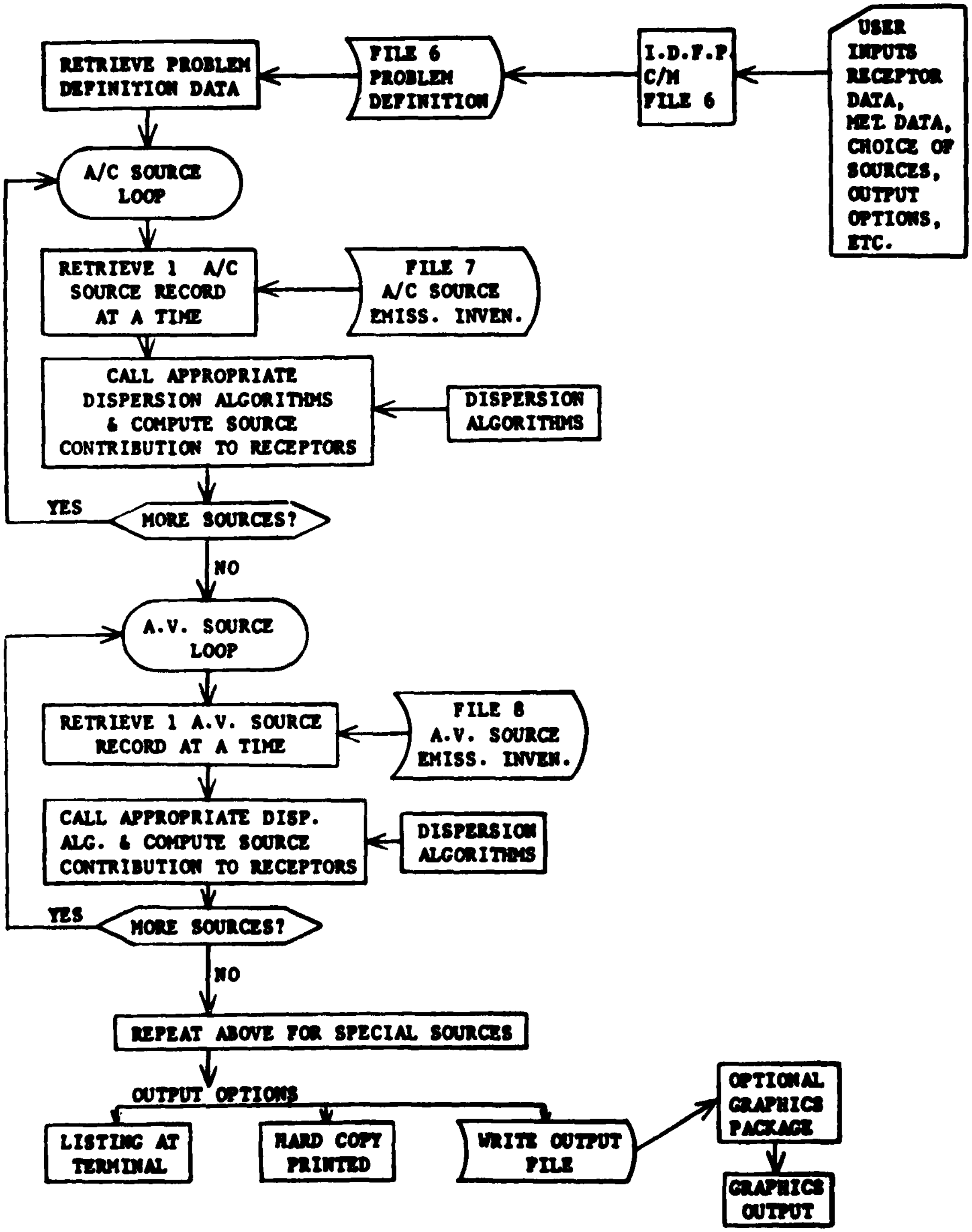
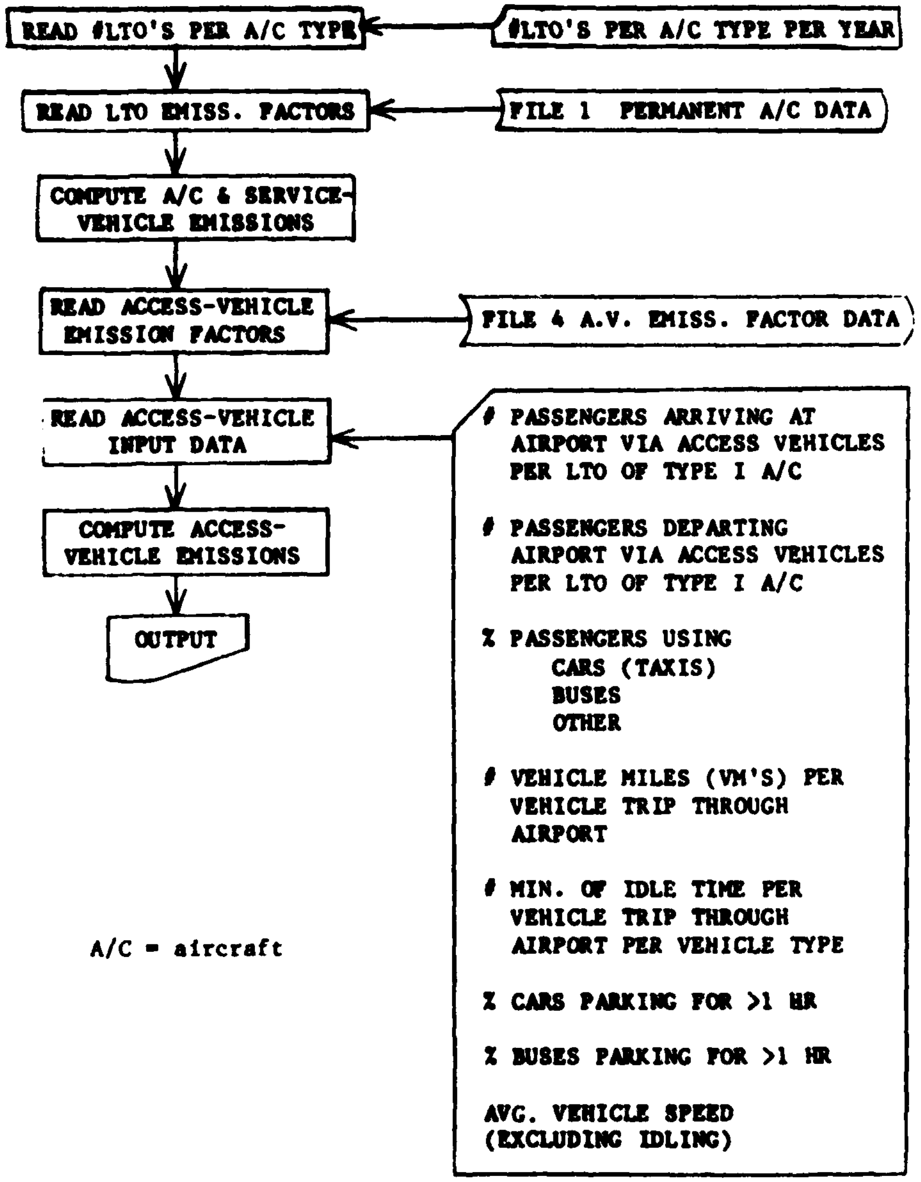


Fig. 7b Macro Flowchart of Short-Term Air-Quality Computations



A/C = aircraft

Fig. 8 Annual-Average-Emission-Estimation Code computational system, passes on information to a subsequent step. It is, in fact, the use of data files that enables the otherwise lengthy computer program to be broken down into small modules that can be handled independently of each other, thus greatly reducing core storage and computer-run time requirements.

Two general types of data files are envisioned for use by the computational system, permanent data files and problem-specific data files. The first type will contain data, such as emission factors and other parameter values, that are not expected to be changed very often. The second type will contain data, such as source descriptions and activity at a particular facility, that would be expected to change at least partially from computer run to computer run.

Strictly as a convenience to users, it is worthwhile considering a data-file-processing computer program that could be used either to create new data files from scratch or to modify or edit existing data files. For even greater convenience, the computer program could be designed to operate in the interactive mode.

An interactive data-file program could operate as follows. It would communicate with a computer-terminal user by issuing messages, asking questions, and making requests for input data. The user would respond by keying in answers, commands, or data. The program should be able to read in data keyed in from the user's terminal or from data files on storage devices. It should also be able to list the contents of data files at the computer terminal, generate hard copy, or write data files onto storage devices. When modifying an existing data file, the program should provide the option of either writing over the old data file or leaving it intact and writing the modified data file onto an entirely new space.

For convenience, it may be worthwhile for the data-file program to be capable of working with a number of different types of data files. For example, it may be useful to have one program that could create or modify several of the data files indicated in Figs. 7a and 7b. To use a program with this capability, the user would simply supply the file type or number upon request by the data file program.

A macro flowchart of an example of an interactive data file program is illustrated in Fig. 9. A detailed-example flowchart is given in Ref. 30.

9.4 SOURCE TYPES TO BE CONSIDERED

Except in special cases, it is generally adequate to treat only the major emitters at an aircraft facility. These include: aircraft operations (especially ground operations), aircraft service vehicles, and civilian and military access vehicles.

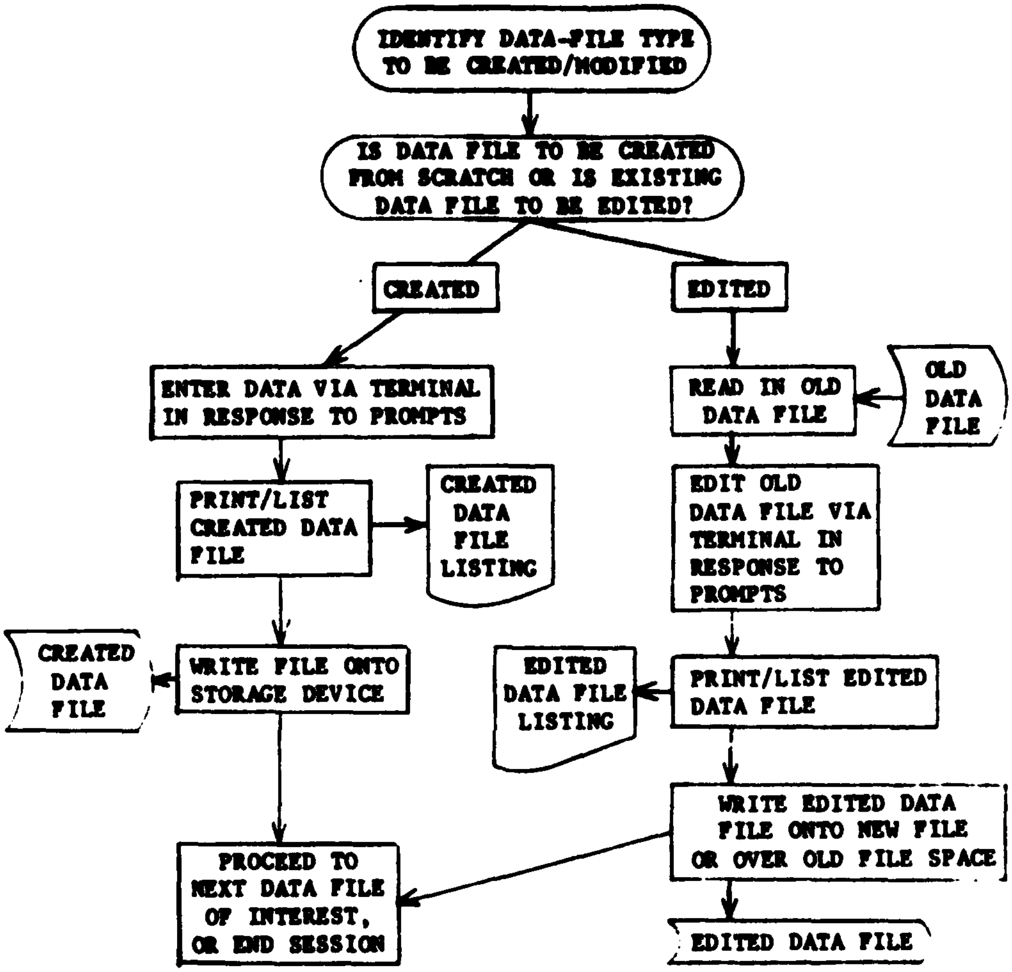


Fig. 9 Macro Flowchart of Interactive Data-File Program (IDFP)

Emissions from airborne aircraft operations are initially much more dispersed than ground-based emissions and therefore contribute negligibly to ground-level pollutant concentrations except in rather special cases (see Sec. 10.3). For this reason, it is not necessary to treat emissions from airborne portions of aircraft LTO cycles in as great detail as ground-based emissions. In addition, emissions from touch-go operations at military training bases will make much smaller contributions to ground-level pollutant concentrations than standard LTO operations. However, for certain purposes, such as estimating impacts of aircraft emissions on photochemical-smog formation and visual-range reduction, etc., it may be desirable to incorporate emissions estimates for these operations and also to provide some crude estimate of source location.

In general, the greatest attention to detail should be given to locating aircraft ground operations. This includes aircraft parking and servicing areas, taxiway segments, aprons adjacent to the ends of runways, where queuing occurs, and runways.

In general, ground operations that deviate from a simple, nonstop aircraft movement should be accounted for, since such operations determine initial pollutant concentration patterns. Particular attention should be given to queuing at runways or service areas and congestion that leads to slower-than-normal taxiing. Provisions for both queuing and reduced taxiing speeds should be incorporated into the model design.

Most other sources, either because of their low emission rates or intermittent operations, do not make significant contributions to overall air quality. However, in certain special cases it may be necessary to treat one or more of the following:

- Hydrocarbon evaporative losses from fuel storage and handling. Parked vehicles are a major source of evaporative losses.
- Emissions from power-generating or space-heating/cooling facilities.
- Incinerators.
- Engine test stands.
- Training fires.

In addition, if the problem involves toxic substances, such sources should be given special treatment. Only emission factors for the "criteria" pollutants should be stored in the computer codes and data files. Special provision should be made for inputting emissions from nonroutine sources directly rather than storing a great variety of special emission factors.

It should be borne in mind that, since there is no health-related standard for hydrocarbons (HCs), it is not necessary to produce detailed dispersion-model estimates for this pollutant category. Of course, HC emissions from combustion sources can be routinely produced, if needed, without any significant additional effort, provided the necessary emission factors are stored in the data files. Evaporative HC emissions are another matter. Fortunately, studies at commercial airports indicate that HC emissions due to evaporation tend to make up a fairly small fraction of total HC emissions due to both combustion and evaporation. Evaporative losses associated with storage tanks in particular constitute a small fraction of total evaporative losses at both commercial and military facilities. Evaporation from parked vehicles exceeds that associated with storage tanks at both types of facilities. Also, depending on how spillage during aircraft filling and fuel line venting is handled, these may constitute important sources of evaporative HCs. See Sec. 10.5 for further details.

9.5 AIRCRAFT SOURCES AND OPERATIONAL MODES

The aircraft operational modes that have been used for modeling military and civilian aircraft facilities are listed in Table 5. Note that there are three special modes unique to air bases, namely idle during arming, idle during disarming, and touch-go training flights. These latter operations do not occur at all military facilities and, when they do occur, they are generally limited to certain squadrons only.

It is important to observe in Table 5 that, basically, only six engine modes are defined for both the military and civilian aircraft operations. Hence, the computer programs used to compute aircraft-source emissions can be structured in essentially the same way for both types of facilities.

For simplicity, it is recommended that emission factors be stored by engine mode on a per aircraft-type basis rather than on a per engine-type basis.

It is further recommended that, for purposes of air-quality computation, only the ground-based aircraft operations be included. (See Sec. 10.3 for a possible exception to this rule.) The airborne operations are known to make only very small contributions to ground-level pollutant concentrations. However, because the user may wish to test this point, or because he may wish to compute the emissions due to airborne operations, it is advisable to provide an option to include the airborne sources and computation of emissions from airborne operations. If such an option is provided, the airborne sources should be restricted to one approach path and one departure path per runway. Each such path could have up to two components, one extending from the ground to some nominal height of say 100 m or 200 m and the other from there to perhaps 1000 m. This is the way the present AVAP model is designed. The AQAM, however, presently uses aircraft-type-dependent approach and departure paths. This latter degree of detail disproportionately increases the computational requirements without attendant significant changes in accuracy of emissions or pollutant-concentration calculations.

With respect to ground-based aircraft sources, it is recommended that two additional sources be considered for inclusion: first, one or two line sources per runway for queued aircraft and second, a short taxiway segment to connect the end of the taxiway with the start end of the runway takeoff roll. Inclusion of these two source types will greatly improve the accuracy of the spatial distribution of the taxiway emissions and consequently will improve the spatial resolution of the pollutant-concentration calculations. During high-aircraft-activity periods, up to 50% or more of the ground-based aircraft emissions can be attributed to such sources (primarily the line sources representing the aircraft queues).

Table 5a Military Aircraft Mode Definitions

	Aircraft Operational Mode	Engine Mode or Thrust Setting	Engine Mode Number
1	Idle at startup	Idle	3
2	Taxi before takeoff	Idle	3
3	Engine check at runway end	Military	4
4	Runway roll	Military or afterburner	5
5	Climbout Step 1	Military or afterburner	5
6	Climbout Step 2	Military or afterburner	5
7	Approach Step 1	Intermediate	1
8	Approach Step 2	Intermediate	1
9	Landing on runway	Mixed	2
10	Taxi after landing	Idle	3
11	Idle at shutdown	Idle	3
Special Modes			
12	Idle during arming	Idle	3
13	Idle during disarming	Idle	3
14	Touch-go runway roll[a]	Idle (?)	3
15	Auxiliary power unit operation	—	6

[a] Touch-go approach path = conventional approach
Touch-go climbout path = conventional climbout but spatially displaced.

Table 5b Civilian Aircraft Mode Definitions[a,b]

	Aircraft Operational Mode	Engine Mode or Thrust Setting	Engine Mode Number
1	Approach step 1	Approach	1
2	Approach step 2	Approach	1
3	Landing	Mixed	2
4	Inbound taxi	Idle	3
5	Idle at shutdown	Idle	3
6	Idle at startup	Idle	3
7	Outbound taxi	Idle	3
8	Runway roll	Takeoff	4
9	Climbout 1	Climbout	5
10	Climbout 2	Climbout	5
11	Auxiliary power unit operation	—	6

[a] Emission factors are stored for each distinct aircraft type, engine mode number (for military: 5 aircraft + 1 auxiliary power unit); for civilian: 5 aircraft + 1 auxiliary power unit), and pollutant type.

[b] User does not have to enter the number of engines per aircraft type.

The short line source connecting the taxiway with the start of the runway takeoff roll is intended to be assigned the emissions associated with the final aircraft maneuvers, generally including a 90° or 180° turn plus a pause prior to takeoff clearance.

The line sources associated with the runway queue would be assigned all extra emissions associated with delays in takeoff due to queuing. A recommended procedure for dealing with runway queues is described in Sec. 9.6.

One additional refinement is recommended for inclusion in treating taxiway segments. A minimum time spent on any segment should be defined (nominally 30 sec). The time spent on a particular segment should be taken as the maximum of this minimum time and the time computed using taxiing speed and segment length. This procedure will avoid any unrealistically short times and allow for aircraft turning.

Generally, the user should be advised to keep the number of individual taxiway line segments to a minimum to reduce computational and input requirements.

9.6 AIRCRAFT QUEUING

In view of the importance of aircraft runway queuing, or aircraft queuing in other locations for that matter, it is worthwhile devoting some detailed attention to it. To cover the widest possible number of situations, it is recommended the user be given three options:

1. Ignore queuing altogether.
2. Include queuing as treated by queuing algorithms incorporated in the computer program.
3. Include queuing, but user supplies his own delay times.

If option 2 or 3 above is selected, the user should then be required to provide the following information:

- For option 2 or 3, give the identification number of one or two taxiway segments that will contain the aircraft queue for each runway. Taxiway segments must always be straight-line segments. Because of taxiway configuration and anticipated queue lengths, it may be necessary to use two taxiway segments to contain the entire queue. (Queuing of greater complexity could be handled, but the queuing algorithm used by the computer code becomes cumbersome.)
- For option 3, give the average delay time for each aircraft entering the queue. If the user selects this option, it

will be assumed that the extra emissions due to queuing are uniformly distributed over the taxiway segments designated by the user for the queue.

If the user selects option 2, the computer algorithm can compute the queue length and compare it with the length of the taxiway segments designated by the user. If the actual queue length differs significantly from the length of the taxiway segment, then the code can define new line sources colinear with the taxiway segments to represent the queue.

The queuing algorithm itself can be based upon the following hypothesis,[31] which is itself based on classical queuing theory. The proposed hypothesis says that all aircraft must stop and wait to be served (by the runway) and that the average number of aircraft waiting to be served is given by:

$$N = \frac{V}{C - V} \tag{1}$$

where:

N = the number of departing aircraft (N_d) waiting to be served plus the number of arriving aircraft (N_a) waiting to be served,

V = the aircraft traffic volume, i.e., the number of aircraft using the runway for both arrivals (n_a) and departures (n_d) per hour, and

C = the runway capacity (the maximum possible number of arriving and departing aircraft that can be served per hour).

Note that this is a steady-state hypothesis. It is assumed that the aircraft traffic volume, V, persists for more than one hour. The actual number of aircraft in the queue will, of course, fluctuate from time to time. N is to be regarded as an average value over the hour.

Since the queue contains both arriving (N_a) and departing (N_d) aircraft in general, and since only the departure queue is of concern, a way must be found to determine the number of aircraft in the departure queue (N_d) separately. Here it is assumed that N_d is proportional to the total number of departing aircraft (n_d). Hence:

$$\frac{N_d}{N} = \frac{n_d}{V} \text{ or } \frac{N_d}{N_d + N_a} = \frac{n_d}{n_d + n_a} \tag{2}$$

It follows that $N_d = \frac{n_d}{V} N$ or, using Eq. 1:

$$N_d = \frac{n_d}{C - V} \tag{3}$$

If all of the aircraft in the queue were of the same type, the length of the departure queue would be given by:

$$L = DN_d \tag{4}$$

where D = distance occupied by one aircraft. If several aircraft types are involved, then the number of aircraft of each type (N_i) must be estimated. Then the length of the departure queue is given by:

$$L = \sum_i D_i N_i \tag{5}$$

The distance occupied by each aircraft type (D_i) can be roughly estimated to be 2 to 2.5 aircraft lengths. The number of aircraft of each type in the queue (N_i) can be roughly estimated from the ratio of the number of that type using the runway for departure (n_i) to the total number of aircraft using that runway for departure (n_d). That is:

$$\frac{N_i}{N} = \frac{n_i}{n_d} \quad \text{or} \quad N_i = \frac{n_i}{n_d} N \tag{6}$$

Finally, the average extra time in minutes per departing aircraft due to queuing, not including the taxi time in the absence of queuing, is the same for all aircraft types and is given by:

$$T = \frac{60N_d}{C} \text{ or } \frac{60}{C} \cdot \frac{n_d}{C - V} \tag{7}$$

The one parameter left to be estimated is the runway capacity, C. A detailed evaluation of C based upon all the available data is beyond the scope of the present effort to outline the new computational system. However, a preliminary review of some data suggests that C is in the neighborhood of 48. For example, if the hourly rate of departures (n_d) and arrivals (n_a) on a runway were 30 and 12, respectively, then from Eq. 1, the average number of aircraft awaiting runway service would be seven. Of these, five would be in the departure queue according to Eq. 3. Consequently, each aircraft that enters the departure queue would have to wait 6.25 min according to Eq. 7.

It is worth noting that if a commercial runway were used exclusively for departures, it could accommodate about 60 aircraft per hour. If it were used exclusively for arrivals, it could accommodate about 40 aircraft per hour, allowing for a separation time of 1.5 min. Hence, the value of C is expected to lie between the values of 40 and 60 aircraft per hour. Generally, runways are not used exclusively for arrivals or departures.

It is worth stressing here that N and T are average values only. Furthermore, the proposed queuing algorithm is only a hypothesis, and the suggested value of C is only an estimate. It is strongly recommended that the hypothesis be tested and that the value of C (which would be stored in the permanent aircraft data file) be evaluated using data for various aircraft facilities.

It should be noted that the AQAM did not use any queuing algorithm and the AVAP model used a queuing algorithm based on O'Hare Airport data only. Unfortunately, very little information exists on the basis for the form of the AVAP queuing algorithm. Essentially, the latter algorithm has the form:

$$T = (\frac{n_d}{3} + 1) \tag{8}$$

where:

T = delay time in minutes per aircraft, and

n_d = number of departures.

For the example given above, if n_d = 30 aircraft per hour, T = 11 min. The AVAP queuing algorithm has a simple linear dependence on the aircraft traffic volume, whereas in the algorithm proposed here (see Eq. 1), V appears in both the numerator and denominator in such a way that as V approaches the runway capacity, C, the number of aircraft in the queue, and therefore the delay time, rapidly increases. This is as expected, since once the traffic flow exceeds the runway capacity, the queue length simply increases with time, and there is no longer any meaning to the idea of an average (steady-state) length of the queue. When V is relatively small compared with C, the delay time is smaller for the proposed algorithm than for the original AVAP algorithm.

The proposed queuing algorithm can be coded in a subroutine called "QUEUE," which would function as follows. QUEUE is called from the Aircraft-Source-Emission-Inventory code whenever the queue flag IQUEFL = 1. If IQUEFL = 0, queuing is ignored. If IQUEFL = 2, the user must input the queuing times QUET (IR) for each runway (IR). All aircraft types suffer the same time delay caused by the queue at a runway.

QUEUE performs the following functions for each runway:

1. It computes the number of aircraft in the queue.
2. It apportions this number amongst the different types of aircraft. The number of aircraft of a given type in the queue is likely to be a noninteger.
3. It estimates the physical length of the queue (QL).

4. It compares QL with the length of the first taxiway segment (TSL) to which the queue is assigned by the user. If QL = TSL ± 20%, a variable called "FLAG" is set = 1, and the extra emissions due to queuing are uniformly distributed over the first taxiway segment used for queuing. If QL < TSL - 20%, FLAG is set = 2 and a new line source, colinear with the taxiway segment, is defined. The extra emissions due to queuing are then assigned to this new line source. If QL > TSL + 20%, FLAG is set = 3, and the queuing emissions are apportioned to the two taxiway segments designated by the user for the queue. The first taxiway segment is assigned emissions corresponding to the fraction TSL/QL of the total delay time. The remainder, namely that associated with the fraction (1 - TSL/QL), is assigned to a new line source of length QL - TSL that is colinear with the second taxiway segment used for queuing.

5. Finally, the subroutine QUEUE returns the value of FLAG along with the value of the extra queuing time per aircraft "TQUE" (for FLAG = 1 or 2) and the value of "TQUEP" if FLAG = 3. "TQUE" and "TQUEP" are the names of variables used to store the delay times assigned to the first and, if used, the second taxiway segments (or line sources) designated by the user to contain the queue.

If a new line source is defined, its second end-point coordinates are identical to those of the taxiway segment with which it is colinear. Its first end-point coordinates are given by:

$$XQ_1 = X_1 + \frac{TSL - QL}{TSL} \quad (X_2 - X_1), \text{ and} \tag{9}$$

$$YQ_1 = Y_1 + \frac{TSL - QL}{TSL} \quad (Y_2 - Y_1)$$

where (X_1,Y_1) and (X_2,Y_2) refer to the first and second end points of the taxiway segment colinear with the new line source, respectively.

A detailed flowchart of subroutine QUEUE is given in Ref. 30.

9.7 AIRCRAFT SERVICE-VEHICLE EMISSIONS

To simplify the computation of emissions from aircraft service vehicles, a single emission factor should be defined that represents the emissions from all service vehicles used to service a single aircraft of a given type. For a civilian airport, the user is asked to enter the number of aircraft of each type that will be serviced during the hour of interest at each aircraft gate area. For a military air base, the user is asked to enter the number of aircraft of each type that will require shutdown servicing during the hour of interest at each aircraft parking area and the number that will require startup service during the same hour (not necessarily the same aircraft). The difference between civilian and military operations is that commercial aircraft are routinely turned around with a single, more or less continuous servicing operation lasting 30-60 min, whereas military aircraft may be serviced in two separate operations, depending on whether the aircraft are transient or permanently assigned to a base. Some of the military aircraft may undergo only one turnaround, while others may be turned around several times in a given day. Hence, whereas one service-vehicle emission factor for each aircraft type will suffice at a commercial airport, separate service-vehicle emission factors for shutdown and startup operations are required for each aircraft type at a military air base.

The military service-vehicle emission factors originally used in AQAM have recently been updated by the staff at Tyndall AFB. These updated factors should be implemented in the new computational system in the permanent aircraft data file.

The civilian service-vehicle emission factors originally used in AVAP were based on a study at O'Hare Airport (circa 1972) and have not been updated. The types of service vehicles used at O'Hare Airport are listed in Table 6 along with the total service times (sum of service times for all service vehicles of the same type) per aircraft type. This information was compiled from questionnaires sent to the various airlines. The emission rates for each of these vehicle types were determined by comparing vehicle characteristics with those of vehicles for which EPA emission-factor data had been published. They should be updated before being incorporated in the permanent aircraft data file of the new computational system.

A procedure for computing aircraft service-vehicle emissions in airport gate areas is outlined below. (A similar procedure could be used for startup and shutdown servicing operations at a military facility.) The objective, of course, is to compute total emissions per pollutant type per aircraft serviced. Since the total time required to perform all services ranges from 30 min to 60 min, service-vehicle emissions must be allocated to the proper model hour.* That is, all aircraft arriving at the airport during a given hour may not all be serviced during that hour. However, other aircraft that arrived during a previous hour may be serviced during the model hour. The user should have the option to specify any number that he wishes for aircraft being serviced during the model hour. That number does not have to bear any relationship to the number of aircraft arriving or departing during the model hour.

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*Hour for which emission calculation is being performed.

Table 6 Total Minutes of Service-Vehicle Operation Allocated to Servicing Each Aircraft Type

Vehicle Type	Aircraft Type 1* 727	2* DC9	3* 737	4* C5	5 BAC	6 YS	7 B9	8 FH	9 TO	10 GA
1 Tractor	66	48	85	55	50	50	0	0	0	0
2 Belt Loader	28	15	30	0	25	25	0	0	0	0
3 Container Loader	6	0	0	0	0	0	0	0	0	0
4 Cabin Service Truck	12	0	15	0	0	0	0	0	0	0
5 Lavatory Truck	15	15	15	10	10	10	5	5	5	0
6 Water Truck	0	10	0	10	10	10	5	5	5	0
7 Food Truck	17	17	20	10	10	10	0	0	0	0
8 Fuel Truck	20	15	15	10	20	20	10	10	10	0
9 Tow Tractor	10	5	5	5	5	5	0	0	0	0
10 Conditioner	0	0	0	0	0	0	0	0	0	0
11 Aircraft Starting Unit, Transporting and Diesel Engines	0	0	0	0	0	0	0	0	0	0
12 Ground Power Unit, Transporting and Gasoline Engines	0	0	0	0	0	0	0	0	0	0
13 Ground Power Unit, Diesel Engine	0	0	0	0	0	0	0	0	0	0
14 Transporter	3	0	0	0	0	0	0	0	0	0

*Also serviced by an auxiliary power unit (APU).

ALGORITHM:*

1. USER INPUTS TOTAL TIMES REQUIRED TO SERVICE 1 TYPE IAC AIRCRAFT WITH TYPE ISV SERVICE VEHICLES
   = SVTIME (ISV,IAC) (min)

2. USER INPUTS EMISSION FACTOR FOR SERVICE VEHICLE TYPE ISV AND EACH POLLUTANT IP
   = SVEMFT (IP,ISV) (g/min)

3. COMPUTE TOTAL EMISSIONS OF POLLUTANT IP FROM ALL SERVICE VEHICLES FOR ONE AIRCRAFT OF TYPE IAC

$$\text{SVEF}(\text{IP},\text{IAC}) = \sum_{\text{ISV}} \text{SVEMFT}(\text{IP},\text{ISV})*\text{SVTIME}(\text{ISV},\text{IAC})$$

4. PRINT OUT SVEF (IP,IAC) OR STORE ON FILE. (This data must be entered into File 1, Permanent Aircraft Data.)

9.8 ACCESS VEHICLES

Access vehicles include all ground vehicles transporting personnel and equipment into, out of, and around an aircraft facility. At a commercial facility this traffic will consist mostly of passenger vehicles. At a military base a larger fraction of the vehicles is likely to be involved in transporting personnel into, out of, and around the base.

In order to compute the emission rates from each roadway segment or parking lot, it is first necessary to define a scenario that describes the nature of the vehicle operations on that segment or lot and the vehicle mix involved. Next, the emission factors for each scenario must be computed. Once the applicable scenarios for each source are defined and the emission factors computed, it is straightforward to compute the emission rates for each source by multiplying the emission factors by the levels of vehicle activity. Unfortunately, the process of computing the emission factors is extremely tedious. Fortunately, existing mobile-source-emission computation routines

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*User may accept default values for both SVTIME (ISV,IAC) and SVEMFT (IP,ISV) or substitute his own input values. Values of SVTIME (ISV,IAC) must be based on observations at airports or air bases. Values of SVEMFT (IP,ISV) can be estimated based on emission factors for sizes of similarly fueled vehicles that are published in Ref. 32. For military air bases, it is appropriate to define two service-vehicle emission factors per aircraft type: a factor for inbound aircraft of type IAC and pollutant IP, SVEFI (IP,IAC), and a corresponding factor for outbound aircraft, SVEFO (IP,IAC).

are now readily available. The procedure recommended here incorporates the use of MOBILE2[33] or, equivalently, output from that or similar computer codes.

A set of emission factors must be computed by MOBILE2[33] for each emission scenario. An emission scenario must be assigned to each physical source (roadway segment or parking lot) so that the appropriate set of emission factors can be applied to each source. Depending upon the variety of combinations of conditions encountered, it may be necessary to define several scenarios to accommodate all of the physical sources at an aircraft facility.

Generally, three types of trips will be encountered at a civilian airport during the course of a one-hour period.

1. A vehicle enters the airport complex, travels to a terminal building along several roadway segments, parks temporarily near the building (often with the engine left idling), then departs from the airport. The vehicle is in the hot-stabilized running condition for the entire trip.

2. A vehicle enters the airport complex and travels to a parking lot where it remains for at least one hour. Emissions result from driving plus hot-soak evaporative HC losses from the carburetor. (A small additional source of evaporative HC losses is due to diurnal ambient temperature changes that result in fuel tank evaporation losses.) During the one-hour period the hot-soak loss predominates.

3. A vehicle leaves the parking lot and then the airport complex. (All operations are assumed to take place in the cold-start running condition.)

In addition, during the hour of interest, a number of vehicles are expected to remain parked in the lots. Only fuel-tank evaporative HC losses are associated with these vehicles.

Depending on the design of the access-vehicle roadway system, the same roadway segment may serve both the parking lots and the through traffic. Hence, vehicles in both the cold-start and hot-stabilized running conditions will occupy this segment simultaneously. Such a mix can be easily handled through the scenario parameters required as input to MOBILE2.

The four vehicle operating modes of interest are:

1. Cold-start condition — vehicles leaving parking lots.

2. Hot-start condition — following short shutdown interval.

3. Hot-stabilized condition — all vehicles entering airport.

4. Idle at hot-stabilized condition -- all vehicles entering airport.

The following types of emission factors must be determined from MOBILE2 runs for each scenario type:

1. Driving emissions (for each pollutant type, for each vehicle type) (g/VMT)* CO,NMHC,NOX.

2. Idle emissions (for each pollutant type, for each vehicle type) (g/min) CO,NMHC,NOX.

3. Hot-soak evaporative losses from carburetor for each hot-soak period (g/hot soak) NMHC.

4. Fuel-tank-breathing evaporative losses (g/hour) NMHC.**

9.8.1 Scenario Type Definition

Each scenario type is defined using the following quantities:

1. Region of country.

2. Calendar year.

3. Average vehicle speed over source (roadway segment or parking-lot lanes); either a single value for all vehicle types or up to eight values for separate vehicle types.

4. Ambient temperature.

5. Percentage of VMT on source in cold-start running condition.

6. Percentage of VMT on source in hot-start running condition (MOBILE2 assumes % cold start + % hot start + % hot stabilized = 100%).

7. Vehicle mix (percentage of VMT on source by vehicle type).

8. Correction factors to basic emission factors.

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*VMT = vehicle miles traveled (number of vehicles × length of roadway segment in miles).

**Items 3 and 4 are required for each vehicle type and can be determined from MOBILE2 output using a special procedure described in Sec. 9.8.2.

In addition to the above quantities, it is also necessary to specify the number of trips per day (actually equivalent to the number of hot-soak periods per day) and the average daily mileage (see Sec. 9.8.2).

9.8.2 Procedure for Determining Evaporative-Loss Emission Factors

MOBILE2 requires the input of two special quantities for each scenario: the number of trips per day and the average daily mileage. These two quantities are not used to compute the driving emission factors. They are only used by MOBILE2 to convert the units of the fuel-tank HC breathing loss from grams per day to grams per mile and the units of the carburetor hot-soak HC loss from grams per hot soak to grams per mile. Unfortunately, the latter units are not the units needed by the new computational system to compute evaporative losses from access vehicles. The required units are:

For carburetor hot-soak loss: grams per hot soak

For fuel tank evaporative loss: grams per hour

In other words, MOBILE2 computes the quantity:

$$E = \frac{a + Nb}{L} \quad . \tag{10}$$

where:

E = evaporative emissions (g/mi),

a = diurnal average fuel-tank breathing loss (g/24 hr),

N = number of trips or hot soaks per day,

b = hot-soak carburetor evaporative loss (g/hot soak), and

L = total number of miles traveled per day.

What is needed for access-vehicle emission computations are the separate quantities a and b. These two quantities can be obtained from the results of two separate MOBILE2 runs as follows. For the first run, set the number of trips, $N = 0$, and the number of miles traveled per day, $L = 1$. Then the output of MOBILE2 will be $E_1 = a$. For the second run, set $N = 1$ and $L = 1$. Then the output of MOBILE2 will be $E_2 = a + b$. Given these two outputs, E_1 and E_2, the separate quantities a and b are computed as:

$$a = E_1 \text{ and } b = E_2 - E_1 \tag{11}$$

where a is fuel-tank breathing loss in grams per day, and b is the hot-soak loss in grams per hot soak. To get the breathing loss in units of grams per hour, simply divide a by 24. A flowchart illustrating a computational procedure for determining a and b is given in Fig. 10.

9.8.3 Access-Vehicle Physical-Source Types

Two types of physical sources are used for access vehicles: (1) straight-line roadway segments (may contain several parallel lanes) and (2) square-area parking lots (several may be required to cover irregularly shaped parking lots). Two types of information are required for each source type: (1) physical description of source and (2) traffic information.

Physical Description

1. Source type (1. Roadway, 2. Parking lot)

2. If type 1: elevation > 0, above grade
   = 0, at grade
   < 0, below grade
   overall roadway width
   number of lanes
   lane width
   end-point coordinates (center of roadway cross-section at each end of segment)

3. If type 2: number of levels
   overall height (= 0, if only ground level)
   length of side of square area
   coordinates of center

Traffic Information (for a one-hour computation)

1. Scenario type (a number identifying the applicable scenario emission factors from MOBILE2)

2. For source type 1 (roadway segment):

   - Number of vehicles/hour of each type
   - Number of minutes of extra idle time/vehicle/vehicle type

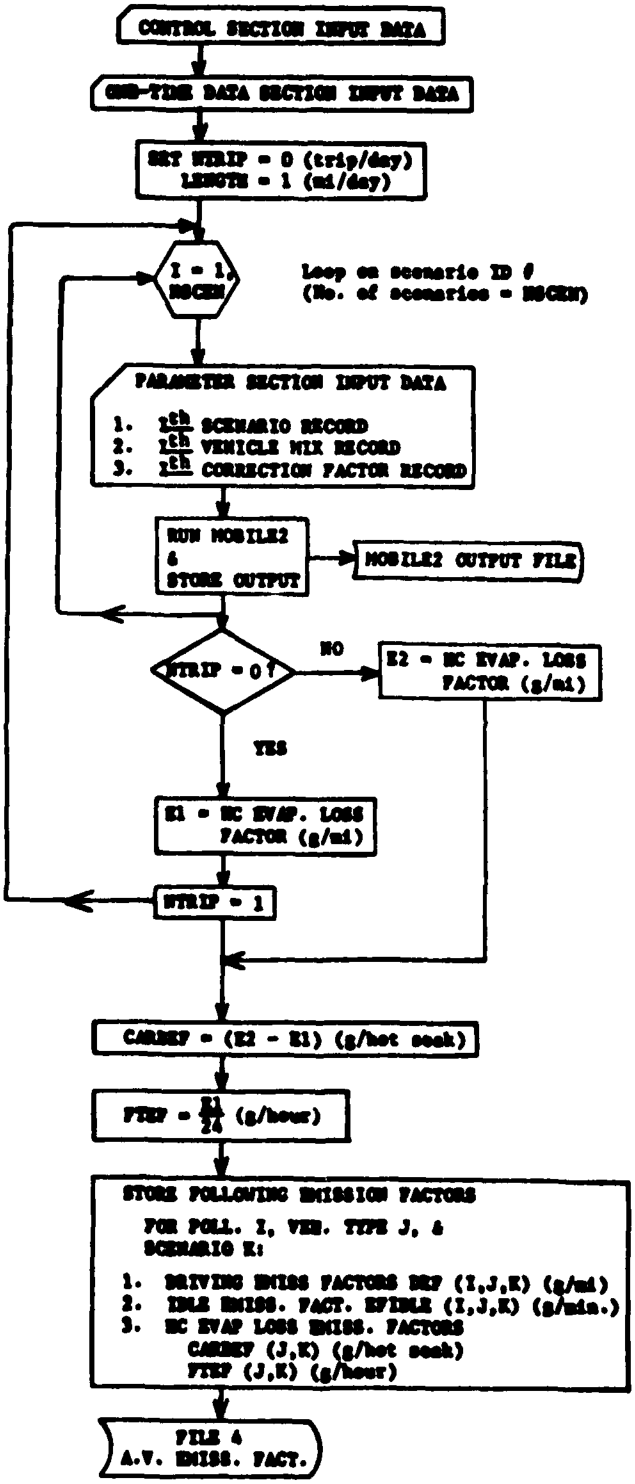

Fig. 10 Emission-Factor Computation Procedure Using MOBILE2

3. For source type 2 (parking lot):

   - Number of vehicles of each type entering lot during hour (assume all are in hot-stabilized running condition). Each such vehicle will have driving emissions, idle emissions, hot-soak carburetor evaporative HC emissions.

   - Number of vehicles of each type leaving lot during hour (assume all are in cold-start running condition). Each such vehicle will have cold-start driving emissions and cold-start idle emissions. Unfortunately, MOBILE2 does not produce cold-start idle-emission factors. Hence, extra driving emissions may be introduced to compensate.

   - Number of vehicles remaining parked during hour (fuel-tank evaporative HC emissions only).

   - Average inbound mileage (measured along path followed by average vehicle).

   - Average outbound mileage (augmented by additional mileage to account for extra idle time if any).

9.8.4 Outline of the Computation of Access-Vehicle Emission Rates

Figure 11 outlines the overall procedure for computing emission factors using MOBILE2 and source emission rates. Guidelines for selecting input parameter values for running MOBILE2 are given in Tables 7a and 7b. The emission-factor computational procedure is outlined in somewhat greater detail in Fig. 10. A detailed flowchart showing the computation of access-vehicle source emission rates is given in Ref. 30.

9.9 HYDROCARBON EVAPORATIVE LOSSES DUE TO FUEL STORAGE AND HANDLING

As indicated earlier, the evaporative HC emissions tend to be a small fraction of the total HC emissions due to combustion and evaporation. Nevertheless, in some cases, the user may wish to include an estimate of emissions from this source class, which includes fuel storage and handling. The original AQAM included a detailed treatment of evaporative HC emissions using essentially the procedures outlined below. The AVAP model ignored all evaporative losses.

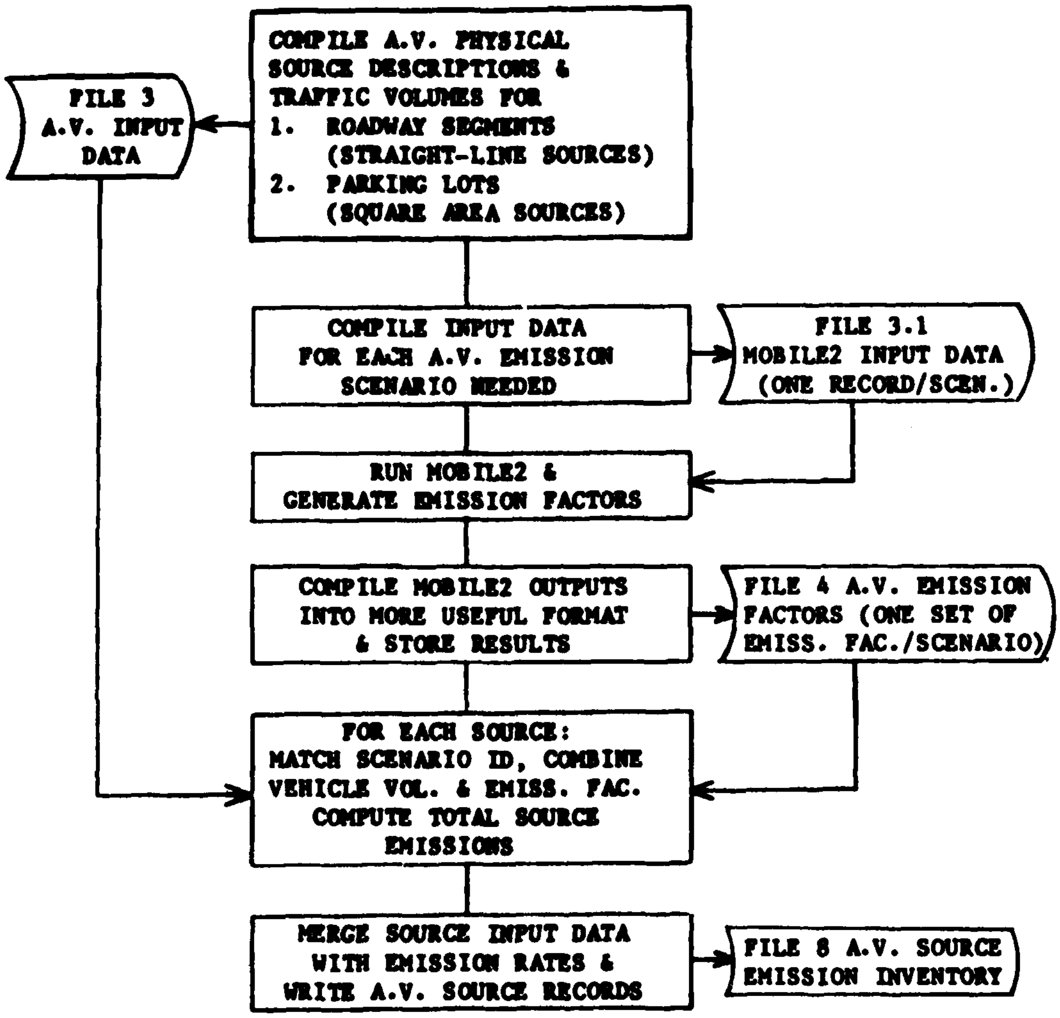

Fig. 11 Macro Flowchart of Access-Vehicle Source-Emission-Rate Computation

There are four types of evaporative losses at a typical aircraft facility:

1. Breathing losses due to diurnal temperature changes that result in emissions from fixed-roof storage tanks as well as tank trucks and vehicle fuel tanks that do not have vapor-control systems.

2. Working losses due to displacement of vapors during filling operations where vapor-control systems are not used.

Table 7a Input Data for MOBILE2 Computations: Control-Section Inputs[a]

Variable	Recommended Input Value	Meaning
SPDFLG	0	Indicates user will use a single average speed for all vehicles on roadway section
VMFLAG	1	Indicates user will enter own VMT mix in PARAMETER SECTION. This will enable user to define as many distinct vehicle mixes as are needed to describe all access-vehicle roadways.
ALTFLG	0	MOBILE2 emission factors will be used.
IMFLG	0	No inspection/maintenance credit.
ALHFLG	1	User will utilize additional correction factors (see MOBILE2 Manual).
IFORM	0 or 2	Indicates user wants numerical output for subsequent use by other computer codes.
PRTFLG	0	Indicates user wants output of all available pollutant (THC,CO,NOX) emission factors.
ICEVFG	3	User supplies number of trips per day and mileage per day to compute evaporative HC emission factor. User wants separate output of these emission factors.
IDLFLG	1	User wants output of idle emission factor.
NMHFLG	1	User wants output of NMHC in lieu of total hydrocarbon (THC) emission factor.

[a] See Ref. 33.

Table 7b Input Data for MOBILE2 Computations: Parameter-Section Inputs and Flags[a]

Record	Variable	Meaning
SCENARIO		One record for each scenario.
	IREJN	Flag identifying geographic region.
	CY	Last two digits of calendar year.
	SPD	Single average route (roadway-segment) speed. If the fraction of idle time to total time on roadway segment is substantially different from that used in the MOBILE2 assumptions, then the excessive idle time should be treated separately. This extra idle time may be combined with the idle emission factors to compute the additional idle emissions on the roadway segment.
	TAMB	Ambient temperature.
	PCCN	Percentage of VMT in cold-start mode by noncatalytically equipped vehicies.
	PCHC	Percentage of VMT in hot-start mode by catalytically equipped vehicles.
	PCCC	Percentage of VMT in cold-start mode by catalytically equipped vehicles.
VMT MIX		If VMFLAG = 1, user must supply fraction of total VMT traveled by each vehicle type. This feature allows user to simulate a broad range of mixtures of vehicles on public as well as limited-access roadways used by cargo and service vehicles.
ADDITIONAL LIGHT-DUTY GASOLINE-POWERED-VEHICLE CORRECTION FACTORS		If ALHFLG = 1 or 2, user must supply appropriate correction factors (see MOBILE2 Manual).

[a] See Ref. 33.

3. Standing storage losses due to poor seals on floating-roof storage tanks.

4. Spillage.

The first three types of losses can be estimated with the use of well-known equations that require information about the tanks as well as some meteorological information. The required formulas are:

Standing Storage Losses

$$SL = \frac{42}{365} WK_1 D^{1.5} \left(\frac{P}{14.7 - P}\right)^{0.7} V_w^{0.7} C_1 C_2 C_3 \qquad (12)$$

where:

SL = standing loss (lb/day),

W = liquid density (lb/gal),

K_1 = tank construction factor,

= 0.045 for welded tanks,
= 0.13 for riveted tanks,

D = tank diameter (ft),*

P = true vapor pressure of the bulk liquid at its average storage temperature (psia),

V_w = average wind speed (mph),

C_1 = tank seal factor (for simplicity adopt only one value for each tank farm),

= 1.0 for tight-fitting, modern seals,
= 1.33 for loose-fitting seals (typical of those built before 1942),

C_2 = fuel factor,

= 1.00 for gasoline,
= 0.96 for naphtha (JP-4),
= 0.83 for kerosene,

---

*If $D > 150$ ft, use $D(150)^{0.5}$ in lieu of $D^{1.5}$.

= 0.79 for distillate oil, and
= 0.75 for crude oil,

C_3 = tank-color factor (for simplicity use 0.95 for all tanks),

= 1.0 for light gray or aluminum finish,
= 0.9 for white,

Vapor Pressure

$$P(T) = \exp(\alpha - \beta/T) \tag{13}$$

where:

P(T) = vapor pressure (psia) as a function of ambient temperature T,

T = ambient temperature (°A), and

α and β = parameters that depend on the fuel type.

Breathing Losses

$$BL = \frac{42}{365} WK_2 D^{1.73} \left(\frac{P}{14.7 - P}\right)^{0.68} H^{0.51} \Delta T^{0.5} C_4 C_5 \tag{14}$$

where:

BL = breathing loss (lb/day),

K_2 = liquid-dependent factor,

= 0.014 for crude oil,
= 0.019 for distillate oil,
= 0.020 for kerosene,
= 0.023 for JP4,
= 0.024 for gasoline,

H = average vapor space height (ft) (select one value for entire base),

ΔT = average diurnal temperature variation (°F),

C_4 = finish factor, which varies from 1 to 1.58 (for simplicity choose one representative value for entire base), and

C_5 = adjustment factor for tanks <20 ft in diameter.

For tank trucks, use:

$$H = \frac{4\ (1 - C_6)TC}{\pi D^2} \tag{15}$$

where:

C_6 = ratio of amount of fuel left in tank to tank capacity, and

TC = tank capacity.

Working Losses

$$WL = K_3 WPVK_4/365 \tag{16}$$

where:

WL = working loss (lb/day),

K_3 = liquid-dependent factor,

= 2.25×10^{-4} for crude oil,
= 2.76×10^{-4} for distillate oil,
= 2.95×10^{-4} for kerosene,
= 3.00×10^{-4} for gasoline,
= 3.24×10^{-4} for JP-4,

V = annual gallons of liquid pumped into tank, and

K_4 = turnover factor based on number of tank turnovers/yr.

Turnover Factor

$$K_4 = (30.34/TO) + 0.157 \tag{17}$$

where:

TO = number of turnovers per year.

$= V/C_T$, and

C_T = tank capacity,

or alternatively,

$$K_4 = (30.34\ C_T/V) + 0.157 \tag{18}$$

9.9.1 Possible Sources of Evaporative Losses

1. Fixed-roof tanks — breathing losses, working losses, and spillage.
2. Floating-roof tanks — standing storage losses and spillage.
3. Tank trucks -- breathing losses, working losses, and spillage.
4. Jet aircraft fuel tanks -- breathing losses, working losses, and spillage (including drainage of fuel lines).
5. Piston-engine aircraft — carburetor and fuel tank losses and spillage.
6. Access and aircraft service vehicles — carburetor and fuel tank losses and spillage.
7. Other sources.

MOBILE2 may be used to generate carburetor and fuel-tank losses for various vehicle types (see Sec. 9.8).

In addition to the above sources, there are also HC evaporative losses associated with a variety of nonaircraft-related operations, including dry cleaning, paving, and spraying and finishing of surfaces. One additional aircraft-related source is deicing. The contribution of these sources is small, but the user may wish to include such sources under the "OTHER SOURCES" category for completeness.

9.9.2 User Input Requirements

In principle, to compute evaporative-loss rates, the user must supply meteorological data, including temperature (T), wind speed (V_w), and diurnal temperature variation (ΔT), and complete descriptions of every source. In practice, there are far too many sources to treat each one on an individual basis. Furthermore, since dispersion calculations are not necessary for evaporative HCs and since they only account for on the order of 10% of the total HC emissions anyway, the locations of individual sources are not important. Hence, it is recommended that the individual sources be aggregated into the following areas:

1. Storage-tank farms.

2. Ground-vehicle filling and service stations, including areas where tank trucks are filled.

3. Ground-vehicle parking areas (do not double-count evaporative losses from access vehicles).

4. Aircraft parking and service areas (or gate areas).

For each of these four areas, the following information is required:

1. <u>Storage-Tank Farms</u> (working, breathing, standing, and spillage losses):

   NLOC1 = no. of locations

   X(I),Y(I) = coordinates of center of farm I

   NDIA(I) = no. of different diameters at farm I

   DIA(I,J) = value of diameter I at farm J

   FINFAC(I,J) = fixed-roof-finish factor of diameter I at farm J

   ANNGAL(I,J) = # gal pumped/yr into fixed-roof tanks of diameter I at farm J

   CAP(I,J) = capacity of tanks of diameter I at farm J

   CONFAC(I,J) = construction factor of floating-roof tanks of diameter I at farm J

   SEAL(I,J) = seal factor for floating-roof tanks of diameter I at farm J

   NFXTKS(I,J,K,L) = no. of fixed-roof tanks of construction type I, storing liquid J, having diameter K, at farm L

   NFLTKS(I,J,K) = no. of floating-roof tanks storing liquid I, having diameter J, at farm K

   SPILL1(I,J) = # of gal of liquid I spilled at farm J per day.

2. <u>Ground-Vehicle Filling and Service Stations</u> (working and spillage losses):

   NLOC2 = no. of locations

   X(I),Y(I) = coordinates of center of station I

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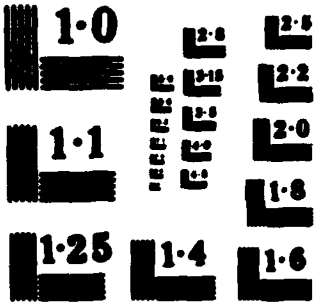
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THRUPUT(I,J) = # of gal of liquid of type I pumped at station J per day

VTKFIL(I,J) = # of lb of vapor displaced while filling vehicle tanks, per 10^3 gal of liquid of type I pumped at station J

SPILL2(I,J) = # of lb of liquid spilled, per 10^3 gal of liquid of type I pumped at station J.

3. Ground-Vehicle Parking Areas

NLOC3 = no. of parking areas

X(I),Y(I) = coordinates of parking area I

NVEH(I,J) = no. of vehicles of type I parked in lot J per day

NHOTSKS(I,J) = no. of hot soaks of vehicle type I in lot J per day

4. Aircraft Parking and Service Areas or Gate Areas

NLOC4 = no. of aircraft parking areas

X(I),Y(I) = coordinates of area I

NACRF(I,J) = no. of aircraft of type I refueled in area J

AVRFRT(I,J,K) = average # of gal of liquid I pumped into aircraft type J in area K per day

ACFIL(I,J) = # of lb of vapor displaced, per 10^3 gal of liquid of type I pumped into an aircraft of type J

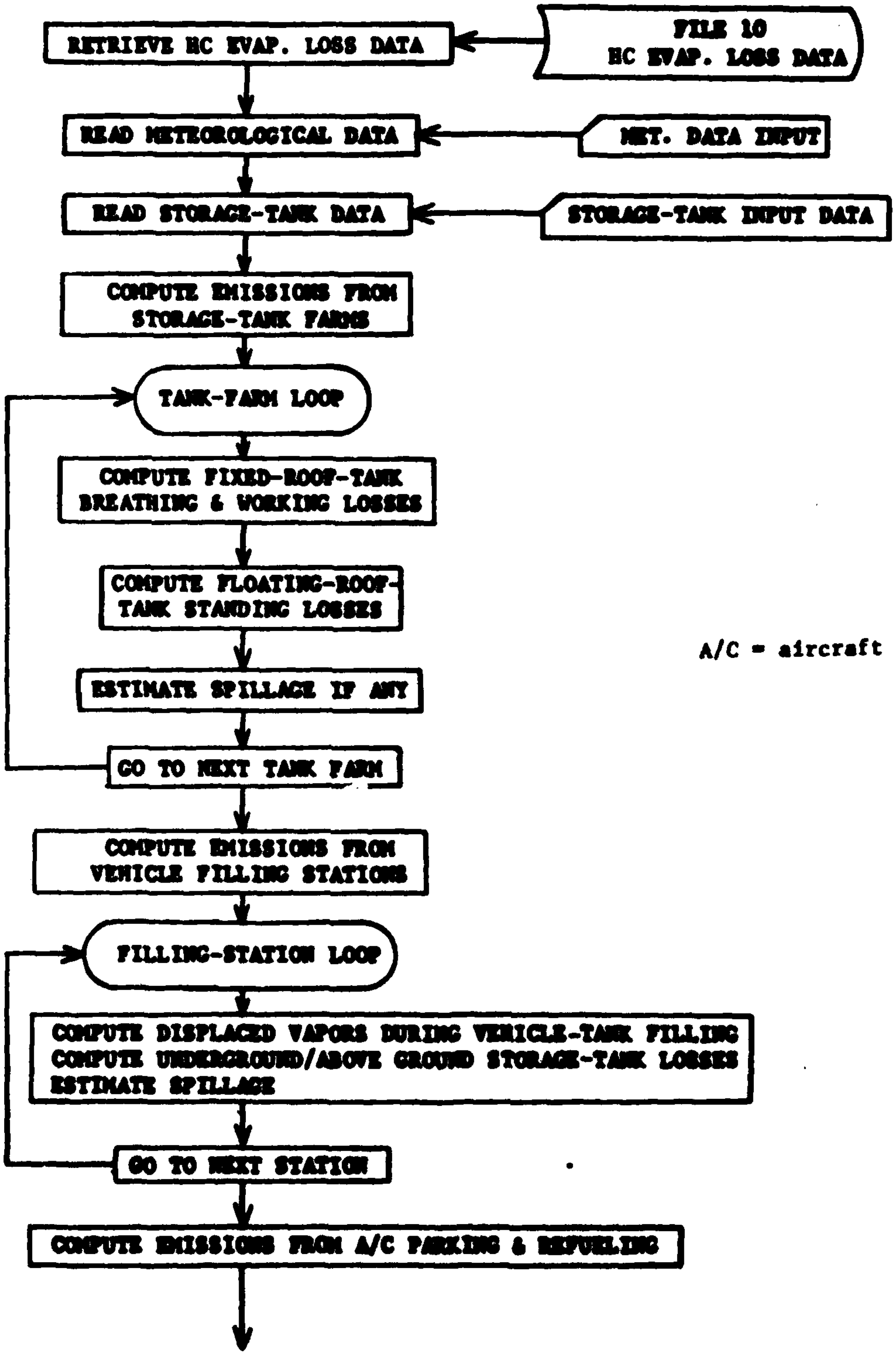
SPILL3(I,J) = # lb of liquid spilled, per 10^3 gal of liquid of type I pumped into an aircraft of type J

9.9.3 Outline of Hydrocarbon Evaporative-Loss Calculations

Figure 12 shows a macro flowchart of a procedure that can be used to compute HC losses due to evaporation. Care should be taken not to duplicate evaporative losses from vehicles already included under access vehicles. No detailed flowcharts have been constructed for the evaporative loss calculations because of the uncertainty of the actual need to perform such calculations. However, if the need arises, such a flowchart could be constructed in a simple, straightforward manner using the equations and user-supplied inputs defined earlier in this section.

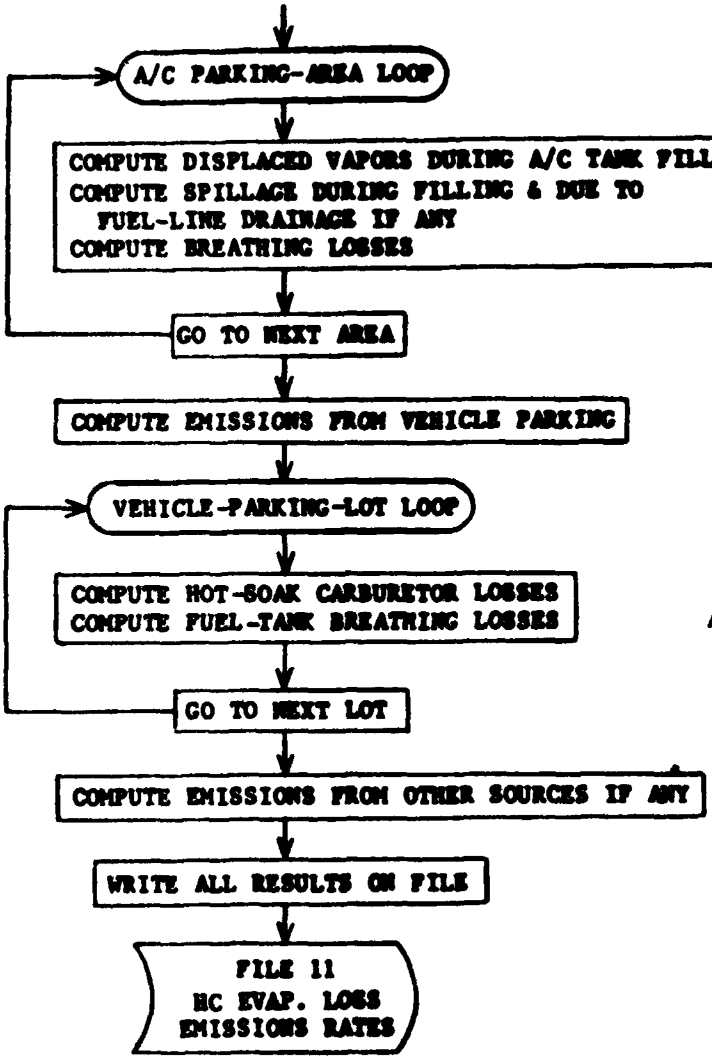
9.10 OTHER SOURCES

It goes almost without saying that, in addition to the major source categories discussed in Sec. 9.9, there are numerous other sources that may



A/C = aircraft

Fig. 12 Macro Flowchart of Hydrocarbon Evaporative-Loss Calculations



A/C = aircraft

Fig. 12 (Cont'd)

operate in or near an aviation facility. Rather than burden the model and the computer with a myriad of details to try to cover all of these source types, it seems more prudent to provide the user with the option of being able to add additional sources for which he must perform his own independent emission-rate estimates using emission factors from AP-42.[32] These emissions, together with the other necessary source-related input data, could then be incorporated into the emission models to be accumulated with other source emissions or to be placed in the special-source emission inventory file for use by the dispersion algorithms.

The structure of the special-source emission inventory file is described in Ref. 30, along with those of all the other source files required by the new computational procedure.

10 SENSITIVITY OF EMISSIONS CALCULATIONS TO INCLUSION OF VARIOUS SOURCE TYPES

10.1 INTRODUCTION

Because the compilation of an emission inventory at a military or civilian airport is a manpower-intensive undertaking, it is important to recognize which emission sources are most important. Unfortunately, there is no simple, unique answer to this question. The relative importance of a particular source type depends on the pollutant of interest, mode of operation of the source, and a number of facility-dependent factors, including facility geometry, source mix, and operational procedures. The question is further complicated by the purpose to be served by an emissions calculation. For example, whereas the overall contribution to such regional impacts as visibility degradation and photochemical smog formation may be relatively significantly influenced by aircraft airborne operations, the ground-level concentrations of primary pollutants (CO, NO_x, etc.) are more influenced by nearby ground-level emissions from aircraft (during taxiing, queuing, etc.). Hence, in seeking guidance on how best to expend efforts on the compilation of an emission inventory, the purpose for the calculation should be given proper consideration.

With these considerations in mind, it is possible to develop some general guidelines regarding the importance of including certain source types or modes of operation on the net emission inventory. In the sensitivity analysis reported here, emphasis is placed on the percent contribution of individual source categories and modes of operation to the overall emissions from an airport or air base. It is also possible to examine the impact of various emission source terms on the air quality (i.e., pollutant concentrations), although considerably more effort is required since one must then consider the type of dispersion algorithm to be used, the meteorological conditions, the positions of receptors relative to sources, the mix of sources, and the levels of source activity. Although no air-quality calculations are used in the present sensitivity analysis, the importance of emissions from selected source types to air quality is examined with the help of a combination of linear emission density calculations (emissions per unit length of a line source) and other straightforward source-receptor considerations.

The approach used here primarily involves the use of previously reported results (although not necessarily reported in the open literature) of emission calculations for a number of civilian and military facilities using AVAP and AQAM, respectively, and also the use of simple emission estimates based on the use of standard LTO cycles. While the latter is much simpler, the former provides more realistic estimates of the importance of sources at actual facilities because measured times-in-mode are used for each facility.

10.2 OVERALL EMISSION SOURCE CONTRIBUTIONS AT CIVILIAN AND MILITARY FACILITIES

Table 8 shows the results in metric tons per year (t/yr) of reported emission calculations at four major civilian airports and one military air base using the AVAP and AQAM emission models, respectively. Four source categories are indicated: aircraft, aircraft service vehicles, base or access vehicles, and stationary sources. This table clearly demonstrates the dependence of the percent contribution of a given source class to the overall emissions on pollutant and facility. For example, base and access vehicular traffic make up 21-59% of the NO_x emissions. It should be noted that, with the exception of the Williams AFB data, all vehicle emission data are pre-1975. Hence, the current vehicular emission contributions are expected to be somewhat smaller. This is confirmed by a study[34] that estimated the vehicular emissions to be 45% of the total CO and 9% of the total NO_x produced at Dulles International Airport in 1976 and 36% of the CO and 7% of the NO_x in 1980. Table 8 also shows that when compared with THC emissions from evaporation and combustion, evaporative losses vary from 7% to 28% of the total at civilian airports and 62% of the total at Williams AFB. Of this 62% contribution at Williams, 76% was due to spilling during aircraft refueling and venting of aircraft fuel lines.

For civilian facilities, the aircraft contribution ranged from 22% to 58% of the total CO emissions and from 59% to 78% of the total NO_x emissions. Hence, aircraft are the major source of NO_x emissions and a significant source of CO at airports. At Williams AFB, which is a training base for pilots of fighter aircraft, aircraft contribute 72% of the CO and 39% of the NO_x. Aircraft also contribute the major portion of HCs. Hence, from the point of view of photochemical smog precursors, aircraft are the major contributors at airports. From the point of view of local direct pollutant impacts (e.g., CO concentrations), aircraft are significant, but given the proximity of the public to vehicular traffic, the latter is likely to be a more significant contributor to local ambient CO levels.

10.3 EMISSIONS FROM AIRBORNE VS. GROUND-BASED AIRCRAFT MODES

An emission-model-independent and facility-independent way of examining the relative importance of airborne vs. ground-based aircraft emissions is to compare the percent emissions from various modes of a standard LTO cycle. Standard LTO cycles are defined for military aircraft in Refs. 35 and 36 and for civilian aircraft in Ref. 37. A standard LTO cycle, which may or may not be aircraft-type specific, consists of a specification of the engine thrust settings (or modes or fuel flow rates) and the times spent in each of a sequence of several aircraft operational modes. Table 5 in Sec. 9.5 lists the typical military and civilian aircraft operational modes. Reference 35 contains tabulations of times-in-modes for a number of military aircraft. These latter data are based on data gathered at air bases. Similar data are

Table 8 Pollutant Emissions by Major Source Category at Several Major Facilities (t/yr)

Source	CO	Combustion HC	Evaporative HC	NO_x	TSP	SO_x
Williams AFB						
Aircraft	1966	253	414	50.3	2.2	24.4
Service Vehicles	60	4	—	1.2	1.0	0.3
Traffic	568	69	67	49.0	24.0	21.0
Facilities	150	10	62	30.0	1.0	82.0
Total	2744	336	543	130.5	28.2	127.7
O'Hare Airport						
Aircraft	8279	4888	75	2913	493	
Service Vehicles	3292	735	—	211	8	
Traffic	3650	624	282	468	29	
Facilities	15	15	145	139	209	
Total	15200	6260	500	3730	739	
Washington National Airport						
Aircraft	1638	388		1096	187	
Service Vehicles	1396	193		63	5	
Traffic	4443	629		412	23	
Facilities	-	-		-	-	
Total	7477	1210	475[a]	1571	215	
Atlanta Airport						
Aircraft	4959	2415		2072		
Service Vehicles	1626	224		57		
Traffic	1870	211		212		
Facilities	136	53		313		
Total	8600	2900	375	2654		

[a] From Ref. 26.

Sources: Williams AFB, Ref. 37; O'Hare Airport, Ref. 6; Washington National Airport, unpublished results obtained as part of work on updated assessment of air pollution impacts at major airports [see Ref. 13]; and Atlanta Airport, Ref. 38.

available by aircraft class for civilian aircraft and average values are reported in Ref. 32. For many purposes, estimates of aircraft emissions can be based on the use of such LTO-cycle data.

10.3.1 Military Aircraft Operations

For purposes of comparing airborne and ground-based emissions, Table 9 contains a tabulation of emissions by pollutant and selected mode for several military aircraft types. Airborne CO and HC emissions constitute only 2-7% and 1-9.4% of the total LTO-cycle emissions, respectively. On the other hand, airborne NO_x, TSP, and SO_x emissions constitute 29-51%, 28-54%, and 23-36% of the total LTO-cycle emissions, respectively. Hence, in terms of mass of emissions only, the pollutants fall into two groups — those for which airborne emissions are relatively unimportant, namely CO and HC, and those whose airborne emissions are relatively important, namely NO_x, TSP, and SO_x.

Somewhat better insight into the question of which aircraft modes are most important can be gained by examining the linear emission densities associated with the line sources used to represent the various aircraft modes. The linear emission density (ρ) is defined as the pollutant emissions per unit length of the line source (g/km). In reality, ρ is rarely independent of position along a line source. This is especially true for runway line sources used to represent the takeoff and landing modes. However, for present purposes it is satisfactory to consider the linear emission densities of taxiway segments, queuing lines, and segments of approach and departure paths to be approximately constant. Given this assumption, comparisons can readily be made between the linear emission densities of these line sources. It is also worth noting that, when comparing total emissions per mode, it is necessary to specify the total times spent in each mode. In the case of comparing linear emission densities, neither the times in the modes nor the lengths of the line sources are required. Furthermore, whereas total emissions cannot be directly related to air quality, because the spatial distribution of the emissions is not specified, linear emission densities can be directly related. That is, line sources having the same orientation relative to a receptor will produce roughly the same pollutant concentrations if their linear emission densities are equal, assuming plume dynamics are not significantly different. Below, comparisons will first be made of linear emission densities without regard to line source orientation. Later, the effect of orientation will also be considered. Before proceeding with these comparisons, the following quantities should be defined. If:

E_T = emission rate in taxiing mode (g/s),

S_T = taxiing speed (km/s), and

ρ_T = linear emission density (g/km),

Table 9 Percent of Total LTO-Cycle Emissions due to Selected Military Aircraft Modes of Operation

	Attack		Bomber		Fighter		Trainer
Mode	A7	A37	B52D/F	C5A	F5	F15	T38
CO Emissions							
Idle at Startup and Shutdown	54	26	22	28	18	31	18
Taxiing	37	54	53	66	59	49	65
Climbout	0.3	4	0.6	3	4	7	4
Approach	2	6	3	6	7	3	6
Total Airborne	2.3	10	3.6	9	11	10	10
HC Emissions							
Idle at Startup and Shutdown	57	29	23	26	21	33	20
Taxiing	40	61	57	63	69	53	71
Climbout	0.05	0.7	0.04	0.2	0.3	0.4	0.3
Approach	0.7	3.0	0.6	5.6	4.1	9.0	3.1
Total Airborne	0.75	3.7	0.64	5.8	4.4	9.4	3.4
NO_x Emissions							
Idle at Startup and Shutdown	4	11	13	4	8	11	9
Taxiing	3	22	27	10	26	18	31
Climbout	23	19	23	40	19	40	21
Approach	9	16	15	2	10	11	20
Total Airborne	32	35	38	42	29	51	41
TSP Emissions							
Idle at Startup and Shutdown	10	5	12	13	5	13	5
Taxiing	7	10	24	32	16	21	19
Climbout	18	26	25	23	26	33	28
Approach	12	16	16	5	10	14	26
Total Airborne	30	42	41	28	36	47	54
SO_x Emissions							
Idle at Startup and Shutdown	26	16	17	16	11	17	11
Taxiing	18	33	38	40	34	27	52
Climbout	11	14	11	17	15	28	18
Approach	13	14	13	6	10	8	8
Total Airborne	24	28	24	23	25	36	26

then $\rho_T = E_T/S_T$. Similar definitions follow for the line source segments representing other aircraft modes of operation. To compare linear emission densities of, for example, climbout paths to taxiways, one can simply compute the ratios of the corresponding linear emissions densities. That is:

$$R_{C_i} = \frac{\rho_{C_i}}{\rho_T} = \frac{E_{C_i}/S_{C_i}}{E_T/S_T}$$

where:

C_i = ith leg of the climbout path,

ρ_{C_i} = linear emission density,

E_{C_i} = emission rate, and

S_{C_i} = average aircraft speed on the ith leg.

Table 10 shows the values of the ratios of NO_x linear emission densities for several airborne line sources for several aircraft types. The subscripts C_1, C_2, A_1, and A_2 refer to the first and second legs of the climbout path and the first and second legs of the approach path, respectively. For military aircraft these legs or line source segments are defined as follows (all angles are aircraft dependent):

1. Approach leg #1 is from 3000 ft to 1000 ft, and leg #2 is from 1000 ft to ground level.

2. Climbout leg #1 is from ground level until the afterburner is shut off, and leg #2 is from afterburner cutoff to 3000 ft. Military thrust setting is used.

Table 10 Ratios of NO_x Linear Emission Densities

Aircraft	ρ_{C_1}/ρ_T	ρ_{C_2}/ρ_T	ρ_{A_1}/ρ_T	ρ_{A_2}/ρ_T
F5 and T38	1.125	0.46	0.125	0.125
T37	0.71	0.57	0.14	0.14
F4	2.38	1.88	0.51	0.48
C130H	0.84	0.44	0.10	0.08
C141	2.47	2.08	0.97	0.71

As can readily be seen from the results in Table 10, the NO_x linear emission densities for airborne aircraft line sources range from a small fraction of to two and one-half times as large as the taxiway linear emission density. The highest and second highest values of the ratios occur for the first and second legs of the climbout paths, respectively, regardless of aircraft type. Hence, all other things being equal, NO_x emissions from climbout path line source segments would be expected to have comparable air-quality impacts to NO_x emissions from taxiways. Of course, all other things are not equal. These line sources are generally not oriented in the same way relative to receptors. Firstly, and most importantly, climbout paths are, of course, inclined at an angle to the ground, whereas taxiway emissions are at ground level. Secondly, plume dynamics are expected to be somewhat different for low-speed ground-level and high-speed airborne aircraft plumes. A detailed dispersion model calculation would be required to properly determine the effects of these differences. However, one can easily appreciate the fact that since airborne plumes must grow in the vertical direction in order to impact ground-level receptors, their impact at ground-level will be smaller than for plumes emitted at ground level. Hence, on this basis, taxiway NO_x emissions will have greater impacts than climbout NO_x emissions on ground-level receptors equidistant from the sources. The term equidistant is critical here because climbout paths (at least their lowest portions) could, in principle, pass closer to the public than taxiways. Hence, if the public resided immediately adjacent to the lowest legs of the climbout paths, the air-quality impacts could be greater for those paths than for taxiways. Combined with runway emissions, the climbout leg #1 emissions may not be insignificant in such situations. How important the corresponding air-quality impacts would be would require calculations with a dispersion model or measurements.

10.3.2 Civilian Aircraft Operations

The following discussion is based primarily on emissions computed in connection with a study to update the assessment of air-quality impacts at several major airports.[13] That study included emission and air-quality calculations for a one-hour period at each of four commercial airports. Table 11 gives the times and runway activities used. The fractional numbers given for numbers of arrivals and departures arise from the way the AVAP model distributes aircraft to the runways that are used for a particular wind direction. The particular hour used for each airport was selected on the basis of high (but not necessarily peak) aircraft activity and the probability that "worst case" (i.e., low wind speed, particular wind direction, and poor vertical mixing) meteorological conditions were likely to occur. Average times in modes observed separately at each airport were used in these calculations.

Aircraft emissions of CO and NO_x for several airborne and ground-level modes of special interest are listed in Tables 12 and 13 for the four civilian

Table 11 Aircraft Activity Used in the One-Hour Emission Calculations at Commercial Airports[a]

Airport	Time of Day	Wind Direction Quadrant	Runway No.	No. of Arriving Aircraft	No. of Departing Aircraft
DCA	9-10am	1	1	20.1	19.7
			2	2.9	3.3
ORD	8-9am	2	2	15	-
			5	15	-
			6	15	-
			7	-	34.5
			8	-	34.5
JFK	7-8pm	3	1	2.9	8.4
			2	5.8	4.2
			7	11.6	12.6
			8	8.7	16.8
LAX	8-9am	3	1	2.2	0.8
			2	7.3	20.4
			3	13.4	24.5
			4	5.2	4.3

[a] DCA = Washington National Airport; ORD = O'Hare International Airport; JFK = John F. Kennedy International Airport; and LAX = Los Angeles International Airport.

Table 12 Percent of Total Aircraft CO Emissions from Selected Modes at Commercial Airports

Airport	Queuing	Taxiing	Climbout	Approach
DCA	36	25	2	9
ORD	48	38	1	4
JFK	20	10	1	4
LAX	39	44	1	3

Table 13 Percent of Total Aircraft NO_x Emissions from Selected Modes at Commercial Airports

Airpor	Queuing	Taxiing	Climbout	Approach
DCA	6	4	44	13
ORD	8	6	45	7
JFK	3	9	48	6
LAX	5	6	51	5

airports. For convenience, only the percentages of total aircraft emissions are shown. As already indicated for military aircraft, civilian airborne aircraft sources of CO contribute relatively little to the overall aircraft CO emissions according to Table 12. Queuing for takeoff is seen to be a major source of CO emissions. This is particularly significant because queuing line sources are substantially shorter than the combined taxiway line sources. Hence, the linear emission densities for queuing line sources are greater than for taxiways, and it follows that the ground-level air-quality impacts would be correspondingly greater.

Table 13 shows that NO_x emissions are greater for the airborne than for the ground-level modes with climbout contributing the major fractions (nearly 50%). Tables 12 and 13 clearly show that, from the point of view of emissions only, the airborne sources are unimportant for CO emissions but important for NO_x emissions, regardless of the airport. These tables also show that the contributions from various ground-level aircraft modes vary considerably from airport to airport. This is largely due to differences in airport configuration and to the aircraft activity levels used for the emission calculations (see Table 11). O'Hare Airport (ORD) in particular has a relatively large CO contribution from queuing due to the large number of departures from two runways. More will be said about queuing in Sec. 10.4 below.

Although there are differences between civilian and military aircraft modes,* the same arguments regarding linear emission density and airborne vs. ground-level sources apply and will not be repeated here.

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*Only one approach leg (500 ft to ground level) is used in the AVAP model. The first climbout leg extends from ground level to 500 ft and the second from 500 ft to 2500 ft.

10.4 DEPENDENCE OF QUEUING EMISSIONS ON THE QUEUING ALGORITHM

The queuing algorithm currently used in the AVAP code has the following form:

$$T_q = \frac{n_d}{180} + \frac{1}{60} \tag{19}$$

where T_q is the average time (hr) spent per aircraft in a departure queue and n_d is the number of departures per hour. The term 1/60 accounts for the time spent on the queuing apron when no aircraft are queued up. An alternative expression for T_q based on queuing theory was discussed in Sec. 9.6. Equation 7 expressed in hours rather than minutes is:

$$T_q' = \frac{1}{C} \cdot \frac{n_d}{C - V} + \frac{1}{60} \tag{20}$$

where T_q' is the time (hr) spent per aircraft in the queue, C is the runway capacity (maximum number of arrivals plus departures that could theoretically be serviced by the runway in an hour), V is the aircraft volume (arrivals plus departures) during the hour, and the term 1/60 has been added to account for time spent on the queuing apron when no aircraft are queued up. The difficulty with using Eq. 20 is that the runway capacity must be specified. As suggested in Sec. 9.6, a value of C = 48 seems to be reasonable, given the limited data. Table 14 gives the values of T_q and T_q' computed from Eqs. 19 and 20, respectively, for the aircraft activity listed in Table 11. It can be seen from these results that the queuing times per aircraft predicted by the AVAP algorithm (Eq. 19) are two to three times larger than for Eq. 20 for the aircraft activities given. This is expected to be the case except when the traffic volume approaches the runway capacity (e.g., during peak traffic periods or periods of reduced runway capacity). In fact, as can be seen from Eqs. 19 and 20, T_q' will be $\geq T_q$ when the following condition holds:

$$\frac{1}{C(C - V)} \geq \frac{1}{180}\ , \text{ or } C(C - V) \leq 180 \tag{21}$$

For C = 48, it follows that $T_q' \geq T_q$ when the total number of arrivals plus departures per hour (V) is greater than or equal to 44.25. Two hypothetical examples are included as the last two entries in Table 14. In both of these examples, the total traffic volume is 45. Hence, $T_q' > T_q$. Furthermore, with V = 45 and C = 48, it is seen that the larger the proportion of departures to arrivals, the larger is the difference between T_q' and T_q. It is not possible, given the present data base, to make a definitive determination of which algorithm best represents the real world. The present calculations only show that calculated queuing time is a sensitive function of the algorithm used and that emissions due to queuing (which are proportional to queuing time) constitute an important fraction of the total ground-level aircraft emissions.

Table 14 Queuing Times Computed with Two Alternative Algorithms (C = 48)

Airport	Runway	No. of Arrivals (n_a)	No. of Departures (n_d)	T_q (hr)	T_q' (hr)
DCA	1	20.1	19.7	0.126	0.067
	2	2.9	3.3	0.035	0.018
ORD	7	0	34.5	0.208	0.070
JFK	7	11.6	12.6	0.087	0.028
	8	8.7	16.8	0.110	0.032
LAX	3	13.4	24.5	0.153	0.067
Hypothetical					
Ex. 1	—	20	25	0.156	0.174
Ex. 2	—	10	35	0.211	0.243

10.5 EVAPORATIVE HYDROCARBON EMISSIONS

Evaporative HC emissions are among the most difficult and tedious emissions to estimate and compile, and are generally subject to large uncertainty. Much of the uncertainty arises from the fact that the least well quantified sources make the largest contributions. This point is well illustrated by some results reported for the Williams AFB Source Emission Inventory.[37] Table 15 lists several sources of HC emissions included in that inventory. Of the 543 t of HC emissions attributed to evaporative losses, 18% are due to aircraft fuel tank venting and 58% are due to spillage during aircraft fuel tank filling. This leaves only 24% due to the myriad other HC storage and handling operations. The evaporative losses attributed to aircraft are quite easy to compile because only one emission factor is required to specify each loss per operation. In contrast, the compilation of the losses due to fuel storage and handling is very complex (see Sec. 9.9). On the other hand, the one number needed to characterize emissions due to aircraft fuel tank venting (~4 L/fill) are quite uncertain. Even if the actual volumes of fuel lost were representative, much of this fluid may end up flowing into drains rather than being evaporated into the atmosphere.

In terms of the total HC emissions due to both combustion and evaporation, the category representing storage and handling constitutes only 15% of the total. Table 16 gives a breakdown of this latter source category. It can be seen from this breakdown that the working losses constitute most of the

Table 15 Hydrocarbon Emissions Inventory Computed with AQAM for Williams Air Force Base (t/yr)

Source	Combustion Emissions	Evaporative Losses
Aircraft Operation	253	
Aircraft Fuel Venting[a]		96.5
Aircraft Spillage[b]		317.5
Aircraft Service Vehicles	3.7	
Base Vehicular Traffic	68.9	
Base Facilities	10.4	
Fuel Storage and Handling (including parked vehicles)		129
Total	336	543
Grand Total = 879		

[a] Assumes 2 L vented per arrival and per departure for most aircraft.

[b] Assumes 4-L spillage per fillup for most aircraft.

Source: Ref. 37.

Table 16 Breakdown of Hydrocarbon Evaporative Losses from Fuel Storage and Handling Other than Aircraft Venting and Spillage Losses (t/yr)

Source	Fixed-Roof Tanks, Working	Fixed-Roof Tanks, Breathing	Floating-Roof Tanks, Standing	Spillage	Other
Storage Tanks[a]	33.4	0.12	2.6		
Filling and Handling	20.3			3.3	
Petroleum Storage		0.002			
Parked Tank Trucks		1.7			
Parked Vehicles		67.1			
Others[b]					1.0
Total	53.7	68.9	2.6	3.3	1.0
Grand Total = 129					

[a] 28 tanks.

[b] Parts cleaning, paint, and thinner.

Source: Ref. 37.

storage tank losses (33.4 t/yr for storage + 20.3 t/yr for filling operations). Breathing losses, by contrast, are relatively small. Evaporation from parked vehicles and tank trucks (68.8 t/yr) constitutes the largest source category.

How do the various source contributions at Williams AFB compare with those at commercial airports? Tables 17 and 18 show the results of evaporative loss calculations for O'Hare International Airport. These tables show that evaporative losses constitute only 7% of the total HC emissions due to combustion plus evaporation. Most of the evaporative losses are due to fuel storage and handling (including evaporation from parked vehicles) at O'Hare in contrast to Williams AFB, where 76% were due to aircraft fuel venting and spilling. At O'Hare, any spilled fuel is assumed to run down the drains in the pavement. The storage tank breathing losses are comparable to the working losses at O'Hare in contrast to Williams where the working losses are predominant. However, in agreement with Williams, evaporation from parked vehicles constitutes the largest source of emissions in the fuel storage and handling class.

Hydrocarbon emissions data for other airports are very limited. Evaporative losses from fuel storage and handling at Washington National Airport (DCA) is reported to constitute 11% of the total HC emissions.[26] No breakdown is available.

At Atlanta Airport (LAX) fuel storage emissions were reported to make up 11% of the total HC emissions.[38] Again no breakdown was reported.

Table 17 Hydrocarbon Emissions Calculated for
O'Hare International Airport (t/yr)

Source	Combustion Emissions	Evaporative Losses
Aircraft Operation	4909	
Aircraft Filling[a]		75
Aircraft Service Vehicles	735	
Access Vehicles	624	
Airport Facilities	15	
Fuel Storage and Handling (including parked vehicles)		428
Total	6283	503
Grand Total = 6786		

[a] Any spillage is assumed to flow down drains.

Table 18 Hydrocarbon Evaporative Losses at O'Hare International Airport due to Fuel Storage and Handling (t/yr)

	Fixed-Roof Tanks, Working	Fixed-Roof Tanks, Breathing	Floating-Roof Tanks, Standing
Storage Tanks	78	34.3	22.1
Service Vehicle Filling	11.4		
Parked Vehicles (carburetors)		282	
Total	89.4	316.3	22.1
Grand Total = 428			

Source: Ref. 6.

It seems clear from the above reported results that HC evaporative losses from fuel storage and handling constitutes a relatively small fraction of the total HC emissions from commercial airports and that a substantial fraction of these evaporative losses at both military and commercial facilities is from parked vehicles. Only in the case of Williams AFB were aircraft venting and spillage major sources of HC emissions.

11 SUMMARY AND RECOMMENDATIONS

The first part of this report addressed the status of the AVAP model and AQAM from the perspective of the modeling requirements of users concerned with air-quality problems in aviation. The approach used was to begin with a brief description of the types of problems likely to be encountered in both the military and civilian sectors, followed by a detailed discussion of those characteristics of the problems that determined the technical requirements for the applicable computational procedures or models. This was followed by a discussion of the operational or user requirements of the models. A review and evaluation of the AVAP model and AQAM was then presented, in which the intended uses, strengths, and weaknesses were described. Finally, the methods used by the AVAP model and AQAM to treat various aspects of the emission or dispersion calculations were compared, and the best methods were selected, or alternatives were recommended where appropriate.

The latter portion of the report addressed the future of the AVAP model and AQAM. From the evaluation given in the first part of the report, it was clear that future efforts were required in a number of areas, including:

- Incorporation of technical improvements.
- Updating of documentation to remove inconsistencies with versions of the computer codes currently in use.
- Rectification of the problem of usability of the computer codes.

Because of the number of interrelated problems and decisions required, a systematic approach to the problem was developed. The "decision tree" that resulted is regarded as a first step towards systematically laying out which alternatives are available and what decisions are required. This device should at least simplify the decision-making process by clarifying the types of tasks that naturally follow from various alternative paths.

The final section of the text was devoted to an outline of a proposed new computational system that should alleviate at least some of the problems identified in earlier sections. Two objectives were paramount in the new design: to make the model easier to use and to be able to implement the model on modern, small computers. In the process of designing the new system, it was found that not only could those objectives be met, but that in some respects the model could even be improved technically. Only the emission or front-end portion of the new system has been addressed in this report. Reference 30 contains detailed flowcharts and other information needed to guide the development of the actual computer codes for the emission portion of the model. The design of the dispersion portion of the new system remains to be undertaken.

The remainder of this section concerns recommendations for future work. These recommendations are divided into two groups: those that pertain to application-type tasks, such as the development and testing of computer codes for the new computational system, and those that concern future R&D efforts. The overriding recommendation is that both types of efforts be pursued in parallel to avoid future shortcomings in either usability or technical quality.

With respect to the applications-related issues, it is strongly recommended that the new computational package be adopted in a form similar to that outlined in Sec. 9. In particular, it is important to completely separate the emissions computations from the dispersion computations. It is also important to make use of the modular nature of the code and the data-file structure. These structures will greatly reduce the computer-core-storage and run-time requirements. Further, every effort should be made to maintain the same overall structure in both the military and civilian versions of the emissions portion of the system. It would be desirable to use the same programming language for both versions, if possible.

Before the emission portion of the new system can be fully implemented, several small tasks should be undertaken. These include the following:

1. Service-vehicle emission factors should be updated.

2. The proposed queuing algorithm should be evaluated using available or new data from military and commercial facilities. Queuing data has been taken at Williams AFB and at several commercial airports.

3. Aircraft emission factors should be updated, and new aircraft types should be added.

4. Approach- and departure-path parameters should be selected as defaults. Some sensitivity tests regarding the impact of airborne aircraft operations on ground-level concentrations should be conducted.

Preliminary design of the dispersion portion of the new computational system should be undertaken as early as possible, so that it can be ready for implementation soon after the emission portion. The dispersion package will require a driver code that can read in the meteorological data, read in the source data (preferably one source at a time), select the appropriate dispersion algorithms, and output the results. It is recommended that the dispersion package be an amalgam of the best features of both the AVAP model and AQAM and that it incorporate refinements already developed but not previously implemented.

Before completing the design of the new dispersion package, it is recommended that the following R&D tasks be completed:

5. Compare computations using Brubaker's advanced single-aircraft-plume research model[17] with treatments of line-source emissions used by the AVAP model and AQAM. Determine under what conditions the more sophisticated modeling approach is required.

6. Utilize the high time-resolution data obtained at O'Hare Airport, together with refinements of the data analysis techniques developed in connection with the O'Hare program,[17] to obtain optimum values of parameters needed to define aircraft takeoff-plume behavior.

7. Critically review the surface observations at Dulles and Washington National, together with the tower measurements at Dulles, to determine to what extent, if any, better definitions of aircraft plume behavior can be obtained for the following aircraft modes: taxiing, queuing, and takeoff. Include an evaluation of the types of analyses performed and the degree of completeness of the analysis. (Not all data were analyzed in detail. Some data received very little attention.) Also determine if the data themselves contain the necessary characteristics to warrant the use of more-sophisticated analysis techniques.

8. On the basis of the results of tasks 5-7 above, evaluate the need, if any, for additional field experiments designed to further elucidate aircraft plume behavior.

9. Critically review all data related to plume dynamics, including effects of plume rise, initial plume dispersion, enhanced vertical dispersion, wind direction relative to aircraft-exhaust velocity, aircraft mode of operation, etc. Prepare recommendations for parameterizing these effects and for additional analyses of existing data or for acquisition of new data. Incorporate parameterizations into the Joint Air Quality Modeling Package.

10. Critically review the advantages, if any, of incorporating recent AMS recommendations regarding alternative stability-classification schemes and dispersion parameters. Consider additional measurement burdens for research and regulatory applications.

11. Develop an alternative to the Nozaki equation as a default for estimating the hourly average mixing depth. Acquire appropriate data sets from representative sites around the country for testing purposes.

After completion, each portion of the new system should be carefully tested and then the portions should be combined and tested together. It is recommended that the new system be compared with either the original AVAP model and AQAM or with data obtained from the field programs at Williams AFB, Washington National Airport, or O'Hare International Airport.

In addition to designing and implementing the new computational system, it is also important to continue R&D efforts to develop the state of the art of aircraft air-quality modeling and to investigate phenomena that were beyond the scope and capabilities of the original AVAP model and AQAM. Therefore, it is recommended that the following tasks be considered for future work:

12. Conduct a field program involving measurements of NO and NO_2 concentrations at various times of the year (especially during the high-O_3 season), using two or more monitoring sites to obtain a more complete characterization of the NO/NO_2 problem. Include examination of effects due to multievent plume interactions and to taxiing and queuing aircraft. Emphasis should be placed on determining potential peak-to-mean ratios, since EPA will probably promulgate annual-average standards that are presumed to protect the public against short-term peak concentrations.

13. Conduct further theoretical studies of NO and NO_2 concentrations to determine if peak NO_2 from aircraft could pose potential short-term health hazards. Examine the applicability of the existing NO/NO_2 conversion data to other civilian and to military facilities. Evaluate differences between civilian and military aircraft, if any, expected as a result of differences in NO_2 to NO emission ratios.

14. Conduct a field and laboratory program to continue preliminary efforts at collection and characterization of organic-pollutant samples at various locations around both civilian and military facilities. Examine both in-plume and ambient samples from various source types.

15. Further elucidate photochemical reaction mechanisms involving aircraft hydrocarbon emissions.

16. Conduct theoretical reactive-pollutant studies in support of both the field and laboratory studies of organic components of aircraft exhaust to determine their impact on photochemical-smog formation.

17. Conduct experimental studies to determine the relationship between aircraft emissions and odors.

18. Investigate the applicability of certain components of the new dispersion package to specialized military applications. Examine ways in which that utility could be enhanced to fully exploit the flexibility of the modeling package.

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