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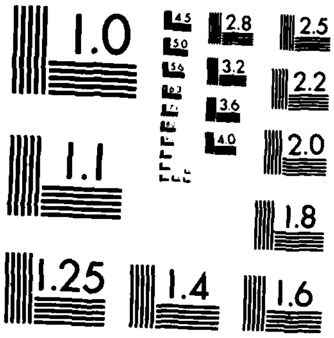

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DEVELOPMENT OF A COMPUTER EMISSION INVENTORY ROUTINE FOR AIRCRAFT GROUND SUPPORT EQUIPMENT

VOLUME I

J. E. SICKLES II
J. G. HAIDT

RESEARCH TRIANGLE INSTITUTE
SYSTEMS AND MEASUREMENTS DIVISION
RESEARCH TRIANGLE PARK, NC 27709

30 SEPTEMBER 1981

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11 AUGUST 1980 - 30 SEPTEMBER 1981

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A computer subroutine was developed to display Ground Support Equipment (GSE) operations data, as well as retrieve and compute the GSE emissions for each aircraft type. This subroutine was embedded into a Source Inventory Program (SIP) designed to quantify the hundreds of air pollution sources typically found on an airbase. Although the SIP was originally intended for use in the extensive Air Quality Assessment Model (AQAM) system, it will also be used in the streamlined Assessment Inventory and Dispersion System (AIDS). AIDS (under development) uses modular interactive microcomputer logic with graphical

input and output capabilities to readily inventory and predict levels of selected air pollutants resulting from Air Force operations and local sources.

This GSE subroutine provides more readily available data as input to air pollution inventories and will simplify manual data collection at the individual base level.

PREFACE

This report was prepared by the Research Triangle Institute, Systems and Measurement Division, Research Triangle Park, NC 27709, under Contract No. F33615-80-D-4000 with the Department of the Air Force, Air Force Systems Command, Aeronautical Systems Division/PMRNB, Wright-Patterson Air Force Base, Ohio 45433 and the Air Force Engineering and Services Center, Engineering and Services Laboratory, Tyndall Air Force Base, FL 32403.

This report covers work performed between August 1980 and September 1981. Project Officers were Captain Daniel D. Berlinrut, AFESC and Lt D. Roe, ASD.

This report consists of two volumes. Volume I provides general information about the project, as well as conclusions and recommendations. Volume II contains the report appendices of raw data.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS the report will be available to the general public, including foreign nations.

This report has been reviewed and is approved for public release.

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SECTION I

INTRODUCTION

The Air Force has developed a model known as the Air Quality Assessment Model (AQAM). This model predicts levels of selected air pollutants resulting from Air Force operations and local sources on short and long term time periods. AQAM is comprised of four smaller routines: Source Inventory Program (SIP), Meteorology Data Program (MDP), Long Term Model Program (LTMP) and Short Term Model Program (STMP). The function of the Source Inventory Program is to format data for input into either STMP or LTMP.

Ground Support Equipment (GSE) operations contribute to the air pollutants released by Air Force bases. These operations are considered in AQAM, but require a fairly comprehensive manually collected data base as input for the SIP. The purpose of the present study is to develop an accurate computer emission inventory routing for GSE and incorporate it into the SIP. This will result in the SIP requiring more readily available data as input, and it will simplify manual data collection at the individual base level. To achieve this end, the present study has the following major goals:

- Design a GSE operations survey form to identify GSE and GSE operations data for various aircraft currently in use by the Air Force.
- Compile and analyze GSE operations data that were received from selected Air Force bases as responses to the previously noted survey form.

- Determine emissions factors for identified GSE.
- Implement the SIP and integrate the GSE operations data and emissions factors into the SIP.
- Develop a routine to display GSE operations data as well as retrieve and compute the GSE emissions for each aircraft type.
- Examine emissions predictions of the SIP with the originial GSE routine and compare them to those of the SIP with the modified GSE routine.

SECTION II

SURVEY FORM, GSE OPERATIONS DATA, AND EMISSIONS FACTORS

A. Survey Form and Responses.

A survey form and instructions for its use were designed to acquire information on the operations and air pollution emissions from aircraft ground support equipment (GSE). Much of the information used in the design of the questionnaire was secured during a visit to Seymour-Johnson AFB. The form was submitted to the Air Force and approved. A copy of this form is attached as Appendix A.

Copies of this GSE Operations Form were distributed by the Air Force and responses were received from 56 bases. The information acquired from these forms was subsequently analyzed. An alphabetized listing of the bases that responded was prepared and is shown in Table 1. The number designations listed in Table 1 for each base will be used throughout this report as base identifiers. A listing of aircraft and the bases where the aircraft are assigned was also compiled and is shown in Table 2.

The data in Table 2 show responses for 30 different types of aircraft (and transients). Four or more responses were received for 12 types of aircraft. Excluding transients and helicopters, this suggests that the following 11 aircraft are most widely distributed among USAF bases: KC135, B52, F4, F106, T38, T39,

TABLE 1. AIR FORCE BASES RESPONDING TO THE GSE OPERATIONS SURVEY.

1. Altus
2. Barksdale
3. Bergstrom
4. Blytheville
5. Cannon
6. Carswell
7. Castle
8. Charleston
9. Davis-Monthan
10. Dobbins
11. Dover
12. F. E. Warren
13. George
14. Griffiss
15. Hill
16. Holloman
17. Homestead
18. Hurlburt
19. K. I. Sawyer
20. Keflavik
21. Kirtland
22. Lackland
23. Langley
24. Little Rock
25. Loring
26. Luke
27. MacDill
28. March
29. Mather
30. Maxwell
31. McChord
32. McConnell
33. McGuire
34. Minot
35. Mt. Home
36. Myrtle Beach
37. Nellis
38. Norton
39. Offutt
40. Patrick
41. Pease
42. Plattsburgh
43. Pope
44. Randolph
45. Robins
46. Scott
47. Seymour-Johnson
48. Shaw
49. Sheppard
50. Tinker
51. Travis
52. Truax
53. USAF Academy
54. Vance
55. Williams
56. Wurtsmith

TABLE 2. AIRCRAFT AND ASSIGNED BASES FROM RECEIVED GSE OPERATION SURVEY FORMS.

Aircraft	Base								
A7	21(2)[a]	21(3)							
A10	9(1)	36(1)							
OA37	52(1)	52(2)							
B52	2(1)	4(1)	7(1)	14(1)	14(2)	20(1)	28(1)	29(1)	34(1)
	45(1)	47(1)	56(1)						
FB111	41(1)	42(1)							
C5	1(1)	11(1)	43(1)	51(1)					
C7	10(1)	30(1)							
C9	46(1)								
C130	18(1)	21(1)	24(1)	31(1)	43(1)				
C131	21(3)	33(2)	52(2)						
KC135	1(1)	2(1)	4(1)	6(1)	7(1)	14(1)	14(2)	20(1)	24(1)
	28(1)	29(1)	32(1)	33(2)	34(1)	41(1)	42(1)	45(1)	47(1)
	51(2)	56(1)							
C141	1(1)	8(1)	31(1)	43(1)	51(1)				
E3	23(1)	39(1)	50(1)						
E4	39(1)								
F4	3(1)	13(1)	17(1)	19(1)	26(1)	37(1)	47(2)	48(2)	
F15	16(1)	23(1)							
F16	15(1)								
F105	33(3)								
F106	7(2)	14(3)	23(2)	25(1)	31(2)	34(2)			
F111	5(1)	35(1)							
H1	12(1)	18(1)	21(1)	42(1)					
H3	21(1)								
H53	18(1)								
O2	9(2)	40(1)	48(1)						
T33	14(3)	19(1)	31(2)	33(3)					
T37	41(1)	44(1)	49(1)	54(1)					
T38	16(2)	39(1)	44(1)	49(1)	54(1)	55(1)			
T39	3(1)	21(1)	39(1)	44(1)	46(1)	55(1)			
T43	29(2)								
OV10	21(2)	40(1)							
TRANSIENT	1(1)	3(1)	6(1)	7(1)	9(1)	10(1)	17(1)	20(1)	34(1)
	39(1)	40(1)	44(1)						

---

[a] A nonunity number in parentheses represents the case where multiple responses were received from a given base. The number identifies that response from among the multiple responses that are being considered.

C130, C141, C5, T33, and T37. It also suggests that averaged GSE operations data from responses for these aircraft representative than the corresponding data from aircraft for which fewer responses were received.

B. GSE Operations Data.

A goal of this project was to update GSE operations data on USAF aircraft considered in AQAM. Of the various types of aircraft considered in the original AQAM, no survey data were received on the following: B1, B57, F100, F101, F102, F104, C121, C97, C119, T41, O1, and DM*. Thus, AQAM GSE operations data cannot be updated for these aircraft. In addition, survey data were received on the following aircraft that were not considered in the original AQAM: FB111, C131, E4, H1, H3, H53, and T43. GSE operations for the aircraft were incorporated into the AQAM SIP.

Survey forms for each base were considered. The following GSE data were examined: hours of operation per LTO, gallons of fuel used per LTO, fuel consumption rate in gallons per hour, the type of fuel used, identification of dependency of operation time on temperature, manufacturer, engine size and horsepower. A master list of GSE was compiled and is shown in Table 3. In addition, each aircraft, its associated GSE and operating times are listed in Appendix B. These results show that the same types of GSE are used to service the majority of aircraft and that GSE falls into several

---

*Dassault Mystere

TABLE 3. COMPREHENSIVE LIST OF GSE.

Type	Designation	Engine Type[a]
Heater	H1	1
	MC1(HTR)	1
	1H1	2
Cooler	MA3	1
	A3	1
	MA1A(CLR)	1
	Cooler-D	2
Generator	MD3	1
	C26	1
	MD28	1
	MB15	2
	90G20P	2
	MB17	2
	Generator-D	2
	AM32A60	3
	AM32A60A	3
	EMU12E	3
Compressor	MC1A	1
	MC2A	1
	MC11	1
	MC1(COM)	1
	MC7	1
	MC1A-D	2
	DR600	2
	MA1A	3
Hydraulic	MJ1(HTS)	1
Test Stand	MJ2A	1
	TTU228E	1
	TTU228E1A	1
	D5	1
	TTU228E1B	2
Bomblift	MJ1(BMB)	1
	MJ1A	1
	MHU83E	1
	MHU83AE	1
	MHU83BE	1
Light Cart	NF2	1
Pressure Tester	M32T1	1
	V4	1
	MB1	1
Jacking Manifold	M27M1	1
Miscellaneous	Blower-G	1
	Deicer-G	1
	Washer-G	1
	Sprayer-G	1
	Empenage-G	1
	Empenage-D	2
	Welder-D	2
Vehicles	Tractor-G	1
	Tug-G	1
	Lift-G	1
	Loader-G	1
	Pickup-G	1
	Van-G	1
	MB4	1
	U18	1
	Lift-D	2
	Loader-D	2
	MB2	2
	TD300SL	2

[a] 1=gasoline piston; 2=diesel piston; 3=turbine

categories according to its use. For the present study the following categories of GSE were devised: heater, cooler, generator, compressor, hydraulic test stand, bomblift, light cart, pressure tester, jacking manifold, miscellaneous, and vehicles. Survey data are incomplete for vehicles and their classification as GSE appears to be unwarranted. Thus, in the remainder of the present study, only the first 10 categories of Table 3 are considered to be GSE.

Based on the information given in Appendix B, average GSE operating types were determined for each aircraft. These results were summarized and are given in Table 4. As can be seen in Appendix B, reported operating times for a given category of GSE can vary by an order of magnitude or more from base to base. This may be attributed primarily to differences in the quality of the survey responses. Other factors that influenced the quality of the data are differences in geographical location (i.e., climate) and differences in base operating procedures.

Next, based on survey results, a compilation of observed fuel consumption rates associated with each piece of GSE and each aircraft was prepared. These data indicate that fuel consumption rate is relatively independent of aircraft. As a result, average observed fuel consumption rates were determined for each piece of GSE. These rates are relatively consistent and show a relative standard deviation of approximately 30 percent. Fuel consumption, as well as other information on the nine most important categories of GSE, are given in Table 5. From this table it is apparent that the same types of engines are used in several GSE. For example, a

TABLE 4. OPERATION TIMES (HOURS) FOR GSE FOR SELECTED AIRCRAFT.

GSE	B52	FB111	A7	A10	A37	T37	C5	C7	C9	C130	C131	C135	C141	T43	KC135
1H	2.69	2.69	0.23	0.23	0.23	0.23	3.21	3.21	3.21	3.21	3.21	3.21	3.21		2.87
1H1	2.69	2.69	0.23	0.23	0.23	0.23	3.21	3.21	3.21	3.21	3.21	3.21	3.21		2.87
MA3	2.20						1.33	1.33		1.33		1.33	1.33		0.78
M03	3.11			0.25	0.25	0.25	3.12	3.12	3.12	3.12	3.12	3.12	3.12		5.16
90G20P	5.61		0.50				7.60			0.		7.60	7.60		5.91
AM32A60	5.06	5.06	4.41	4.41			3.85			0.		3.85	3.85	3.85	4.68
MC1A	1.03	1.03	0.10	0.10	0.10		0.75	0.75	0.75	0.75	0.75	0.75	0.75		0.49
MC11	0.						0.			0.					
MC2A	0.37	0.37	0.16	0.16	0.16		0.92	0.92		0.92	0.92	0.92	0.92		0.32
1MC1A	1.03	1.03	0.10	0.10	0.10		0.75	0.75	0.75	0.75	0.75	0.75	0.75		0.49
MA1A	2.20		0.67				0.46			0.46		0.46	0.46		0.31
TTU228E	0.09		0.14				1.18			1.18			1.18		0.12
MJ1	0.09	0.09				0.14	1.18	1.18		1.18		1.18	1.18		0.12
MJ2A	0.			0.14			1.18			1.18		1.18	1.18		0.12
TTU228E1B	0.09		0.14				1.18			1.18			1.18		0.12
MJ1	3.25		2.11		2.11		0.			0.					
MJ1A	3.25			2.11			0.			0.					
MHU83AE	1.37	1.37	2.04	2.04	2.04		0.			0.					
NF2	3.36	3.36	0.23	0.23	0.23		3.18	3.18	3.18	3.18	3.18	3.18	3.18		4.66
M32T1	0.		0.13	0.13			0.			0.					
M27M1	0.40						0.38			0.38		0.38	0.38		0.19

TABLE 4. OPERATION TIMES (HOURS) FOR GSE FOR SELECTED AIRCRAFT (CONCLUDED).

GSE	F4	F15	F16	F105	F106	F111	T33	T38	T39	H1	H3	H53	02	OV10
1H	0.70	0.70	0.70	0.70	0.70	0.70	0.70		0.70	1.00		1.00	0.	0.
1H1	0.70	0.70	0.70	0.70	0.70	0.70	0.70		0.70	1.00		1.00	0.	0.
MA3	0.58		0.		0.58	0.			0.58				0.	0.
MD3	0.53		0.	0.53	0.53	C.53	0.53	0.53	0.53	0.64	0.64	0.64	0.33	0.33
90G20P	0.	0.07	0.			0.			0.				0.	0.50
AM32A60	1.10	1.10	1.10	1.10		1.10			1.10				0.	0.
MC1A	0.58	0.58	0.58	0.58		0.58	0.58		0.58	0.50	0.50	0.50	0.	0.
MC11	0.		0.		0.58	0.			0.				0.	0.
MC2A	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.50	0.50	0.50	0.50	0.50
1MC1A	0.58	0.58	0.58	0.58		0.58	0.58		0.58	0.50	0.50	0.50	0.	0.
MA1A	0.09		0.	0.09		0.		0.09	0.09				0.	0.
TTU228E	0.30	0.30	0.			0.			0.		0.50	0.50	0.	0.
MJ1	0.		0.		0.30	0.	0.30	0.30	0.	0.50			0.	0.
MJ2A	0.		0.30	0.30	0.30	0.30	0.30	0.30	0.				0.	0.
TTU228EIB	0.30	0.30	0.			0.			0.		0.50	0.50	0.	0.
MJ1	0.52		0.			0.52			0.				0.	0.
MJ1A	0.52	0.52	0.52			0.52	0.52		0.				0.	0.
MHU83AE	0.24	0.24	0.24		0.24	0.24			0.				0.	0.
NF2	1.25	1.25	1.25	1.25	1.25	1.25	1.25		1.25	0.83	0.83	0.83	0.50	0.50
M32T1	0.04	0.04	0.04		0.04	0.04	0.04		0.				0.	0.
M27M1	0.		0.			0.			0.				0.	0.

TABLE 5. SUMMARY OF MAJOR TYPES OF GSE AS IDENTIFIED FROM GSE OPERATIONS SURVEY.

Type	Designation	Fuel			Engine				GSE
		Mogas	JP-4/Diesel	Consumption(GPH)[a]	Piston	Turbine	in^3	HP	Manufacturer
Heater	H-1	✓		3.3	✓		7.1	2.5	Amer.Air Filter
	1-H-1		✓	2.5	✓		17.3	3.6	Davey
Cooler	MA-3	✓		6.3	✓		471	175	Amer.Air Filter
Generator	MD-3	✓		6.7	✓		471	175	Beech
	32A-60		✓	24.6		✓	---	160	Libby
	90G-20P		✓	2.6	✓		284	148	Hobart
Compressor	MC-1A	✓		1.6	✓		107	30	Davey
	MC-1A		✓	1.4	✓		77	18	Davey
	MC-11	✓		1.8	✓		107	30	Davey
	MC-2A	✓		1.1	✓		50	10	Champion
	DR-600		✓	11.3	✓		426	200	Ingersol
	MA-1A		✓	16.2		✓	---	---	Air Research
Hydraulic Test Stand	MJ-1	✓		5.0	✓		314	110	Arnolt
	MJ-2A	✓		7.8	✓		471	175	Sun
	TTU-228E	✓		6.3	✓		471	175	Sun
	TTU-228E18		✓	4.7	✓		318	210	Detroit Diesel
Bomblift	MJ-1	✓		1.2	✓		107	30	Standard
	MJ-1A	✓		1.2	✓		107	30	Standard
	MHU-83A/E	✓		1.0	✓		107	30	Standard
Light Cart	NF-2	✓		1.1	✓		50	10	Amer.Air Filter
Pressure Tester	M32T-1	✓		3.3	✓		471	175	Sprague
Jack	M27M-1	✓		2.6	✓		107	25	HECO

---

[a] Average observed fuel consumption rate based on results from GSE Operations Survey.

471 in^3, 175 HP gasoline engine is used to power an MD-3 generator, MJ-2A and TTU-228E hydraulic test stands, and an M32T-1 pressure tester.

C. Emission Factors.

Item managers for several of the categories of GSE listed in Table 5 are located at Robins, McClellan, and Kelly AF Bases. These individuals were contacted in an effort to identify GSE engine manufacturers. Subsequently, engine manufacturers were contacted in an effort to secure emissions test data (emissions factors). Except for Garrett Air Research and Hatz Diesel, the manufacturers could not supply this information. Emissions data are not available in most cases, because the engines have been in production and/or service for over 20 years and no regulations exist now or at the time of the engine acquisition to require emissions testing. As a result, most of the emissions factors assigned to the GSE were based on the data in Reference 1.

Average emissions factors for selected GSE are listed in Table 6. Emissions factors can be determined on the basis of horsepower and/or on the basis of fuel consumption rate. Using the survey results, both methods were used to determine emissions factors for GSE. Except as noted to the contrary, the values given in Table 6 represent averages of emissions factors determined by the two

TABLE 6. AVERAGE EMISSIONS FACTORS FOR SELECTED GSE.

Type	Designation	Engine Characteristics				Factors (g/hr)				
		in^3	HP	Mogas	Diesel/JP-4	CO	HC	NOx	SOx	Part
Heater	H-1	7.1	2.5	✓		3376	212.0	67	2.1	6.1
	1-H-1	17.3	3.6		✓	64	28.0	291	7.3	21.0
Cooler	MA-3	471.0	175.0	✓		24036	933.0	623	3.9	40.0
Generator	MD-3	471.0	175.0	✓		24124	936.0	625	3.9	40.0
	32A-60	NA	160.0		✓T	1688[b]	14.0[b]	332[b]	79.1	45.0[e]
	90G-20P	284.0	148.0		✓	294	129.0	1355	8.8	97.0
Compressor	MC-1A	107.0	30.0	✓		4685	162.0	122	1.3	7.7
	MC-1A	77.0	18.0		✓	122[d]	65.0[d]	128[d]	5.6	24.0
	MC-2A	50.0	10.3	✓		2466	155.0	49	0.79	4.4
	DR-600	426.0	200.0		✓	527	231.0	2432	28.4	174.0
	MA-1A	NA	NA		✓T	806[c]	6.7[c]	159[c]	37.8	21.0[e]
Hydraulic Test Stand	TTU-228E	471.0	175.0	✓		23141	902.0	600	3.4	38.0
Bomblift	MJ-1	107.0	30.0	✓		4685	162.0	122	0.79	7.8
Light Cart	NF-2	50.0	10.3	✓		2466	155.0	49	0.74	4.4
Pressure Tester	M32T-1	471.0	175.0	✓		21530	846.0	558	2.4	35.0
Jack	M27M-1	107.0	25.0	✓		4367	152.0	113	1.1	7.1

[a] Unless noted otherwise, emission factors were taken from Ref(1) [AP-42]. These factors are the average of factors based on horsepower and on fuel consumption.

[b] Personal communication with Bob Stefun of Garrett Air Research.

[c] Extrapolated from data received from Bob Stefun of Garrett Air Research.

[d] Personal communciation with Joe Lange of Hatz Diesel.

[e] Estimated from oil-fired turbine electric generators Ref(1) [AP-42].

[f] Calculated from fuel consumption and assumed 0.01 wt% sulfur in Mogas and 0.05 wt% Sulfur in JP-4, see Ref(2).

methods. The discrepancies between the two methods generally did not exceed a factor of two, but in a few cases they were as high as a factor of ten.

It should be noted that the SO_2 emissions factors were calculated based on observed fuel consumption rates and assumed 0.01 weight percent sulfur in Mogas and 0.05 weight sulfur in JP-4 (Reference 2). In addition, surfey results indicate that JP-4 is generally used in both diesel and turbine driven GSE. Emissions factors for the turbine-powered GSE burning JP-4 were secured from Garrett Air Research. No emissions factors, however, are available for diesel engines burning JP-4 instead of diesel fuel. Therefore, it was assumed that emissions factors for diesel engines burning diesel fuel are identical to those for diesel engines burning JP-4.

D. Analysis.

Using the observed fuel consumption rates listed in Table 5, the emissions factors in Table 6 were converted into units of Kg/gal. These were averaged for Mogas-, diesel-, and turbine-powered GSE. These average emissions factors are listed in Table 7, along with the corresponding values from AP-42 as

TABLE 7. COMPARISON OF EMISSIONS FACTORS.[a]

Engine	SO_2[b]	CO	HC	NOx	Particulate
Mogas (Gasoline)					
Average[c]	0.000540	2.774	0.1107	0.0703	0.00461
AP-42[d]	----	1.787	0.0618	0.0462	0.00293
AQAM[e]	0.0016	2.405	0.1409	0.0073	0.0168
Diesel					
Average[c]	0.00329	0.0835	0.0382	0.328	0.0254
AP-42[d]	----	0.0462	0.0202	0.213	0.0152
AQAM[e]	0.0012	0.0587	0.0059	0.0117	0.0587
Turbine					
Average	0.00294	0.0625[f]	0.00052[f]	0.0123[f]	0.00165

[a] Units: kg/gal.

[b] Calculated from fuel consumption rate and assumed 0.01 wt% sulfur in Mogas and 0.05 wt% sulfur in JP-4.

[c] Average of emissions factors converted into kg/gal for GSE given in Table 6.

[d] Emissions factors based on fuel consumption rate as given in Reference 1.

[e] Emissions factors given in Reference 3.

[f] Personal communication with Bob Stefun of Garrett Air Research.

indicated in Reference 3. The "average" emissions factors are calculated as the average of emissions factors based on fuel consumption rates and horsepower as given in Reference 1. The "AP-42" emissions factors are calculated from fuel consumption rate emissions factors as given in Reference 1. This accounts for the reasonable agreement between the "average" and "AP-42" emissions factors for both Mogas-and Diesel-powered GSE. The emissions factors used previously in AQAM agree with the "average" values within a factor of 4. For both Mogas-and diesel-powered GSE, the AQAM NO_x emissions factors are over an order of magnitude (factor of 10) less than the "average" values. Thus, the original AQAM and the version modified to incorporate the "average" emissions factors would be expected to be the most divergent for predictions of NO_x concentrations, with the original version predicting appreciably less NO_x than the modified version.

As indicated in Table 2, survey data were most numerous for the KC135. As a result, this aircraft was chosen for detailed examination of GSE emissions. Average GSE operations times for the KC135, as given in Table 4, along with the corresponding GSE fuel consumption rates (Table 5), and emissions factors (Table 6), were used to determine emissions from KC135 GSE operations. Results of this analysis show that for the KC135, generators are the major contributors to GSE emissions, and account for approximately 80 percent of the total CO and HC GSE emissions and for approximately 95 percent of the total NO_x, SO_x, and particulate GSE emissions. Although the exact fractional contributions will vary from aircraft to aircraft, cursory examination of GSE operations data suggests that generators should be a major GSE emissions source for other aircraft as well.

The KC135 was also chosen for analysis of emissions' sensitivity to temperature. Survey results indicate that of the major types of GSE, the operation times of only heaters and coolers were dependent on ambient temperature. Thus, for the KC135, three scenarios were considered: baseline, where operation of neither heaters nor coolers is required; cold climate, where operation of only heaters is required; and warm climate, where operation of only coolers is required. Results from this analysis are summarized in Table 8. These data suggest that for the KC135, temperature-dependent emissions account for less than 15 percent of the total GSE emissions. Thus, within the confines of our model (see Section IIIC for further details), the impact of ambient temperature on GSE emissions is not great.

TABLE 8. ANALYSIS OF TEMPERATURE SENSITIVITY OF GSE EMISSIONS FOR KC135

Scenario	Emissions (g/LTO) CO	HC	NOx	SOx	Part
Baseline	152436	6648	13233	459	1028
Cold Climate	162225	7256	13425	465	1046
	(6)[a]	(8)	(1)	(1)	(2)
Warm Climate	171284	7376	13719	462	1059
	(11)	(10)	(4)	(1)	(3)

[a] Numbers in parentheses represent the percentage increase over the baseline scenario.

SECTION III

ALGORITHM AND SOFTWARE

This section describes the general approach used in treating GSE in the AQAM Source Inventory Program. The treatment, based on an examination of the results of the GSE present Operations Survey, is consistent with the philosophy and existing implementation of the SIP. Meetings conducted with RDV personnel at Tyndall Air Force Base, resulted in a consensus that this approach to GSE emission sources is generally sound and that it has the potential for greatly improving and simplifying the assessment of such sources.

The fundamental aim is to convert summary data on GSE usage--data readily available to airbase personnel--into an allocation of total GSE emissions according to both aircraft type and GSE type. The result is an accurate assessment of GSE emissions, and a valid breakdown of total GSE emissions into their component parts.

The approach for inventorying GSE emissions is based on an algorithm, which attempts to allocate total GSE fuel consumption reported at an airbase, to the types of aircraft, and to the types of GSE used to service these aircraft. Given individual GSE fuel consumption rates, emissions factors can be applied to translate them into emissions of the sort considered by AQAM (carbon monoxide, sulfur oxides, hydrocarbons, nitrogen oxides, and particles).

The algorithm for treating GSE emissions developed here is intended to provide a detailed allocation of both emissions and fuel consumption to individual types of GSE servicing individual types of aircraft on an average, per LTO basis. At the same time, the algorithm attempts to minimize the effort required of data collection personnel in inventorying an airbase.

A. Analysis.

If A denotes the set of individual aircraft types using an airbase, then the total annual GSE fuel consumption is given by Equation (1),

$$G(f) = {}_{a}\sum_{\rightarrow A} G(f,a), \tag{1}$$

where f denotes the type of fuel in question (Mogas, diesel, JP-4, etc.) and G(f,a) is the annual consumption of this fuel by aircraft of Type a. By definition, then, Equation (2) defines $\overline{g}(f,a)$ to be

$$\overline{g}(f,a) = \frac{G(f,a)}{N(a)} \tag{2}$$

the average fuel consumption per LTO if N(a) is the annual number of LOTs of Aircraft a. It is important to recognize that $\overline{g}(f,a)$ is actually a fictitous quantity in the sense that an "average servicing operation" probably never occurs. Its use, however, is justified by the statistical nature of the pollution assessment provided by AQAM.

The $\bar{g}(f,a)$ can be further broken down according to Equation (3)

$$\bar{g}(f,a) = \sum_{e \rightarrow E(f,a)} \bar{g}_e(a) \qquad (3)$$

in which $\bar{g}_e(a)$ represents average fuel consumption per LTO attributable to GSE of Type e. Here $E(f,a)$ denotes the set of all types of GSE consuming fuel of Type f which are used in servicing aircraft of Type a. If, $\pi_e(p)$ denotes the emission factor of GSE Type e for pollutant Type p, then Equation (4) defines $\bar{w}_e(a,p)$ to be

$$\bar{w}_e(a,p) = \pi_e(p)\bar{g}_e(a) \qquad (4)$$

the average quantity of this pollutant released per LTO of aircraft Type a. The desired output of the Source Inventory Program is determined in Equation (5) simply by summing these quantities according to GSE fuel type

$$\bar{W}(f,a,p) = \sum_{e \rightarrow E(f,a)} \bar{w}_e(a,p). \qquad (5)$$

In principle, Equations (1) through (5) can be used to assess GSE emissions in AQAM. Unfortunately, there is neither a convenient procedure for measuring fuel consumption by the individual types of GSE nor even a convenient way to specify the types of GSE used in a specific servicing operation. Depending on a number of factors--ambient temperature, availability of equipment, and servicing procedures peculiar to the various airbases--one can encounter varying collections of equipment being employed from one servicing activity to the next. To circumvent these difficulties, a simplified model for ground servicing activities was employed. The model is approximate but is relatively straightforward to implement and should provide reasonable assessments of GSE emissions.

B. Model.

The GSE model seeks to express the average fuel consumption figures attributable to individual types of GSE, the $\bar{g}_e(a)$ above, in terms of more readily accessible factors. To this end, major elements influencing these quantities are identified below and then combined in such a way that the $\bar{g}_e(a)$ may be estimated from annual airbase fuel consumption figures attributable to ground service operations. Given the $\bar{g}_e(a)$, the desired pollution assessment follows immediately through application of emissions factors (the $\pi_e(p)$ of Equation (4)).

The first element of the model is a GSE catalog which lists, for each of the 10 functional GSE categories (see Table 3), all types of GSE falling in that category which find reasonably widespread use. Each such type of GSE will be identified by model number (or simply name if no confusion results) by engine type (gasoline piston, diesel piston, or turbine), fuel type (Mogas, diesel, JP-4, JP-8), engine displacement (if appropriate), and engine horsepower. (The motivation for including the last four items of information is to allow data gathering personnel to locate equivalent types of GSE in case an airbase uses equipment not listed explicitly.) It is to be noted, incidentally, that multi-functional equipment will have multiple listings in the catalog;

for example, the 32A-60 functions both as a generator and a compressor.

Characterizing each entry in the GSE catalog will be (1) its rate of fuel consumption (gallons per hour or liters per hour) and (2) a set of emission factors specifying the grams of a given type of pollutant produced per gallon or liter of fuel consumed. Five factors will be specified (for carbon monoxide, sulfur oxides, hydrocarbons, nitrogen oxides, and particles) with expansion space for a sixth factor, as yet undefined.

The next element of the GSE model is a specification, for each type of GSE, of a universal service time for each type of aircraft recognized in AQAM. Since actual service times may be highly variable, one strives in setting those universal times merely to reflect the relative length of time each type of GSE would be used during a "normal" operation. There is no necessity for absolute accuracy, only relative accuracy. The fuel allocation procedure described below is intended to adjust the service times to account for annual GSE fuel consumption at an airbase. If the universal service times are proportionally correct, the fuel allocation will also be correct, and ultimately the GSE emissions inventory will be accurate as well. Generation of the universal service times depends on analysis of the GSE Survey results.

A possible source of difficulty inherent in this element of the GSE model is the potentially large number of parameters which must be specified. Given 50 aircraft types and a like number of GSE types, 2500 service times must be determined. Even if a number of these are zero (because GSE of Type e is not used with aircraft of Type a), the resulting data base will likely prove uncomfortably large. To cope with this problem, the possibility of lumping GSE into functional classes (heaters, generators, etc.) and aircraft into service classes (bombers, fighters, etc.) was investigated. In this approach, the universal service time $t_e(a)$ depends only on the class of GSE containing e and the class of aircraft containing a. Given 10 GSE classes and 10 aircraft classes, only 100 service times need be specified.

The elements of the GSE model described to this point are considered to be airbase-independent. The next element of the model, one which accounts for factors peculiar to a given airbase, is a specification of the GSE inventory at the airbase and the usage of this equipment. This inventory, constructed with reference to the GSE catalog described above, lists each type of GSE used at an airbase, its "availability factor," and its usage among the aircraft stationed at the airbase.

The availability factor is intended to account for the possibility that an airbase may possess GSE of different types which are nevertheless functionally equivalent and are used interchangeably depending on availability. For example, the H-1 heater and the 1-H1 heater are interchangeable. If a given airbase possessed 13 of the first and 7 of the second and no preference was given by that base to either, then the availability factor for the H-1 is logically set to

$$\frac{13}{20} = 0.65$$

and that of 1-H1 to

$$\frac{7}{20} = 0.35.$$

Note, however, that both of these numbers properly ignore the fact that neither heater is used in warm weather, since ambient temperature is not a consideration in setting availability factors as defined.

The usage of a given type of GSE among different types of aircraft is indicated by a table with rows corresponding to GSE types and columns to aircraft types stationed at the airbase. A simple check at the intersection of a row and a column signifies that a given type of GSE was used by the airbase to service a given type of aircraft.

It is to be noted that this model assumes that two types of GSE used interchangeably on one type of aircraft are used interchangeably, and in the same proportions on all types of aircraft to which either is assigned. If this assumption proves invalid, the obvious modification corrects the difficulty (availability factors must be entered directly into the usage table) but makes data collection more arduous.

The second airbase-dependent parameter included in the model involves temperature and its effect on the frequency of use of heaters and coolers. Whereas, generators are used for every LTO, heaters find use during only a fraction of the annual LOTS. Thus, the fuel consumption and emissions per LTO of heaters and coolers on an average basis must be reduced correspondingly. To account for this, a second usage, or temperature, factor is introduced which is some fraction between zero and unity for heaters and coolers and is unity for all other GSE functional categories. Although these factors could be estimated in several ways, the most convenient approach for AQAM is to define them in terms of meteorological variables currently input to the Source Inventory Program. Given the annual mean temperature, $\overline{T}$, and temperature variation, $\overline{\Delta T}$, at an airbase, Equation (6) defines the temperature factor

$$\frac{40 - (T - 2\,\overline{\Delta T})}{2\,\overline{\Delta T}} = 1 - \frac{\overline{T} - 40}{2\,\overline{\Delta T}} \qquad (6)$$

for heaters, and Equation (7) defines the temperature factor

$$\frac{T + 2\,\overline{\Delta T} - 80}{2\,\overline{\Delta T}} = 1 - \frac{80 - \overline{T}}{2\,\overline{\Delta T}} \qquad (7)$$

for coolers. The first number is simply representative of the percentage of time the temperature is below 40°F; and the second, the percentage of time the temperature is above 80°F. Here 40°F is chosen as the heating threshold, and 80°F as the cooling threshold; either is susceptible to later adjustment.

In summary, then, the GSE model is based on four elements:

- Universal GSE catalog;
- Universal GSE service times;
- Airbase GSE inventory;
- Airbase temperatures.

These elements are synthesized into an algorithm which creates a GSE emissions inventory at an airbase.

C. Synthesis.

To relate these model elements to the analysis of Section III, the following parameters are isolated and defined:

- the fuel consumption rate, φ_e, for equipment of Type e;
- the universal service time, $t_e(a)$, which reflects the nominal length of time equipment of Type e operates per LTO, when it is used at all, in servicing aircraft of Type a;
- the availability factor, β_e, which reflects the possibility that a substitute for equipment of Type e is available for use;
- the assignment indicator, $i_e(a)$, which is unity of equipment of Type e is used to service aircraft of Type a and is zero otherwise;
- the temperature factor, γ_e, which reflects the influence of ambient temperature on whether equipment of Type e is used; this factor is unity (full usage) except for heaters and coolers.

In terms of these quantities, the average service time (per LTO) of equipment of Type e operating on aircraft of Type a can be expressed by Equation (8)

$$\bar{t}_e(a) = \beta_e i_e(a) \gamma_e t_e(a) \qquad (8)$$

and average fuel consumption, by Equation (9)

$$\bar{g}_e(a) = \varphi_e \bar{t}_e(a). \qquad (9)$$

If $\bar{g}_e(a)$ is determined properly by this procedure, the total fuel consumption figures calculated according to the formulas of Section III should agree with reported fuel consumption figures as shown in Equation (10)

$$G(f) = \sum_{a \to A} N(a) \sum_{e \to E(f)} \bar{g}_e(a), \qquad (10)$$

where E(f) denotes the set of all types of GSE using fuel of type f.* Since such a circumstance is highly fortuitous, a fuel-dependent factor, $\alpha(f)$, is introduced to force the desired agreement in fuel consumption. For GSE of Type e using fuel of Type f, average service times are computed according to Equation (11)

$$\bar{t}_e(a) = \alpha(f)\,\beta_e i_e(a) \gamma_e t_e(a). \qquad (11)$$

Note that $\alpha(f)$ is chosen so that reported fuel consumption, G(f) is equal to computed fuel consumption as defined by Equation (12)

$$(f) = \frac{G(f)}{\sum_{a \to A} N(a) \sum_{e \to E(f)} \varphi_e \beta_e i_e(a) \gamma_e t_e(a)}. \qquad (12)$$

This approach forces an allocation of fuel consumption to individual types of GSE servicing individual types of aircraft.

With the $\bar{t}_e(a)$ or equivalently, the $\bar{g}_e(a)$, now having been computed, the pollution factors contained in the GSE catalog can be used to perform an emissions assessment according to Section III.

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* Introduction of the assignment indicators allows use of larger set E(f) in place of E(f,a).

D. Software.

The original Source Inventory Program has a structure where various modules are successively overlaid on one another such that the program does not require excessive computer memory. This structure was found to be incompatible with the additional data bases required by the new GSE algorithm. That is, if software implementing this algorithm were to be retrofitted to the orignial program in the obvious way, it is likely that the resulting program would grow unacceptably large. The alternative program structure is shown in Figure 1.

For the most part, the modules comprising the new program structure represent nothing more than a rearrangement of codes in the original SIP. The new main program, SRCINV, invokes five successive major overlay programs--FIRST, ACEMIV, ABEMIV, ENEMIV, and LAST--the functions of which should be self-explanatory from the listings contained in Appendix C. With the exception of ACEMIV, which deals with aircraft emission sources, the major overlays and all their supporting routines are comprised of codes virtually identical to the original codes. This is largely true of ACEMIV and its supporting subroutines; the only changes to existing codes in this case are those necessitated by the new GSE algorithm. Thus, only GRDSRV (which accepts GSE input data), GSEFCT (which processes these data), and OACSII and OINCLC (which print the results) show any significant deviations from the original codes.

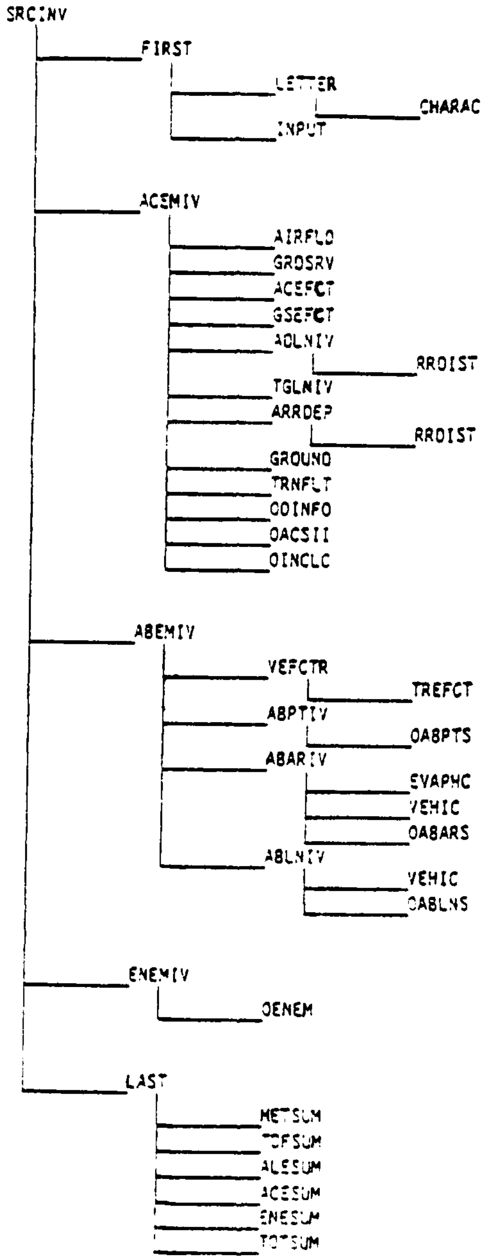

Figure 1. Revised SIP Structure.

E. Input Data.

The new GSE algorithm involves changes only to the Data Sets 2 and 9 of the original program. Thus, Data Set 2 (which allows the user of SIP to alter the standing data bases of the program) has a new element (GSDATA) to treat the GSE data base. Through this additional NAMELIST construction, one can change (or add to) any of the data elements concerning GSE, just as, for example, one can change any of the elements involving aircraft engine data through the EGDATA NAMELIST.

The original Data Set 9, which specified GSE emissions as a function of fuel type and aircraft type, is completely superseded. The new Data Set 9 contains the data specified earlier in Section III. C.

A work sheet, Figure 2, has been constructed to show the data needed for a hypothetical airbase. The left most column is a listing of all GSE identified in the new SIP together with its identification number. (Space is left for the insertion of additional GSE deemed important at a given airbase. This option is not generally recommended to the user, however, because it will likely lead to little improvement in the final results.) GSE items not contained in the inventory of the airbase are simply crossed out as indicated.

The next column of the work sheet specifies the usage accorded to each GSE type, in those cases where two or more types of GSE are interchangeable. Following the usage column are eight columns, each headed by an aircraft type identified in Data Set 5. Below

GSE	USAGE	AIRCRAFT							
		KC135	F106						
1. H1	50.	✓	✓						
2. 1H1	50.	✓	✓						
4. MA3	100.	✓	✓						
6. MD3	100.	✓	✓						
7. 90610P	100.	✓							
8. AM32A60	100.	✓							
10. MC1A	100.	✓							
11. MC11	100.		✓						
12. MC2A	100.	✓	✓						
13. 1MC1A									
14. MA1A	100.	✓	✓						
16. TTU228E									
17. MJ1	100.	✓							
18. MJ2A	100.		✓						
19. ITTU228E									
21. MJ1									
22. MJ1A	100.		✓						
23. MHU83E	100.		✓						
25. NF2	100.	✓	✓						
27. M32T1	100.		✓						
29. M27M1	100.	✓							

MOGAS 153,000 JP4 250,000 Diesel ________

Figure 2. GSE Work Sheet.

each aircraft type a check indicates whether individual types of GSE are used in servicing that aircraft. Blank spaces at the bottom of the work sheet are provided to identify the amount, in gallons, of fuel consumed annually by GSE at the airbase.

Information from the work sheet, Figure 2, is transformed into the new Data Set 9 as shown in Figure 3. Card Type 1 of this data set gives a count of the types of GSE at the airbase together with the fuel consumption figures. Card Type 2, repeated for each type of GSE, specifies the GSE identification number, percentage use, and the aircraft types it is used to service. Comparison of Figures 2 and 3 should be straightforward.

CARD TYPE 1 - [FORMAT(I4,4X,5F8.3)]

```
  18    153000. 250000.
```

CARD TYPE 2 - [FORMAT(I4,F10.0,6X,8I1)]

```
   1       50.      11
   2       50.      11
   4      100.      11
   6      100.      11
   7      100.      10
   8      100.      10
  10      100.      10
  11      100.      01
  12      100.      11
  14      100.      11
  17      100.      10
  18      100.      01
  22      100.      01
  23      100.      01
  25      100.      11
  27      100.      01
  29      100.      10
```

Figure 3. Data Set 9 Construction.

SECTION IV

COMPARISON OF PREDICTIONS OF ORIGINAL AND REVISED SIP

The GSE SIP was implemented on the RTI computer. GSE operations data retrieved from the survey and emissions factors for individual GSE were integrated into the SIP. A routine was developed to display GSE operations data as well as retrieve and compute the GSE emissions for each aircraft type.

Three Air Force bases were chosen for consideration: Grissom, Homestead, and Williams, and SIP data sets were provided by the Air Force at each base. The goal of this portion of the present study was to run the SIP with the original and revised versions of the GSE routine and compare the predictions.

The following discussion describes the information presented in the output listing of the revised GSE routine. Section I of the output has three subcategories: A. Default Information; B. Input Information; and C. Interim Calculations. Section IA simply presents general information and is identical on all output listings. A.1 and A.2 contain engine pollutant information data and engine pollutant emission rates. A.3 and A.4 were added in the present revision and contain GSE pollutant emission data and GSE pollutant emission rates. Section IB presents input data and differs from base to base. B.1 contains information on aircraft activity, parking areas, taxiways, and runways. B.2 was changed in the present revision and contains annual GSE fuel consumption as well as servicing information on each aircraft. B.3 contains aircraft landing and takeoff parameters. Section IC presents interim calculations: C.1 contains aircraft emission factors by aircraft type; and C.2, added in the present revision, contains GSE LTO emissions by aircraft and fuel type.

Section IV of the output, a summary of results, has six subcategories: A. Meteorological Data; B. Temporal Distribution Fractions; C. Aircraft Emissions; D. Airbase Emissions; E. Environ Emissions; and F. Total. Only IV C and IV F are impacted by GSE emissions. C.1 contains a summary of annual emission by aircraft type, and C.2 contains a summary of annual emissions for all aircraft. F.1 is a summary of all annual emissions, and F.2 is an emission percentage breakdown of all sources.

The program output is lengthy. As a result, the changes in the output listing that stem from revision of the GSE routine are identified in Table 9.

TABLE 9. SUMMARY OF CHANGES IN OUTPUT LISTING RESULTING FROM REVISION OF GSE ROUTINE.

Section	Change	Type of Change
I	A.3 Added	Format
	A.4 Added	Format
	B.2 Revised	Format
	C.2 Added	Format
IV	C.1 Revised	Results
	C.2 Revised	Results
	F.1 Revised	Results
	F.2 Revised	Results

The input data sets and output listings are given in Appendices D, E, and F for Grissom, Homestead, and Williams AF Bases. Each appendix contains input data (Sets 2 and 9) and a complete output listing for the original version of the GSE routine. Next, the input data (Sets 2 and 9) and output listing (where different from the original as identified in Table 9) are given for the revised version of the GSE routine.

Using the original and revised routine, predictions of GSE and total base emissions for Grissom, Homestead, and Williams AF Bases were performed (see Appendices D, E, and F). Results from these model runs are summarized in Table 10. For each pollutant, except particulate matter (PM), the revised routine predicted higher emissions than the original routine. Revised PM emissions estimates are, on the average, 60 percent of the original. Revised SOx, CO, and HC emissions estimates on the average exceed the original estimates by factors of 2.7, 2.4, and 1.6, while the corresponding factor for NOx emissions is 8.9. The anticipated impact of the new emissions factors incorporated into the routine was discussed earlier (see Section II. D). Thus, the changes in emissions estimates in the revised routine are consistent with this earlier discussion and appear to result to a large extent from the new emissions factors used in the revised routine.

TABLE 10. SUMMARY OF GSE AND TOTAL BASE EMISSIONS PREDICTED BY THE ORIGINAL AND REVISED SIP FOR GRISSOM, HOMESTEAD, AND WILLIAMS AF BASES.

Base	Version of SIP	Emissions Source	Predicted Emissions[a]				
			CO	HC	NOx	PM	SOx
Grissom	Original	GSE	263	15.7	2.09	2.46	0.30
		Total	767	251	100	12.1	15.6
		Percent[b]	34	6.3	2.1	20	1.9
	Revised	GSE	594	24.9	28.0	2.08	0.77
		Total	1098	260	126	11.7	16.1
		Percent	54	9.6	22	18	4.8
		GSE_R/GSE_O[c]	2.3	1.6	13.3	0.85	2.6
Homestead	Original	GSE	426	26.3	7.14	32.6	0.89
		Total	1659	407	105	75.7	22.0
		Percent	26	6.5	6.8	43	4.1
	Revised	GSE	1068	42.1	50.3	4.22	3.16
		Total	2301	423	148	47.3	24.3
		Percent	46	10	34	8.9	13
		GSE_R/GSE_O	2.5	1.6	7.1	0.13	3.6
Williams	Original	GSE	151	9.5	3.15	2.34	0.72
		Total	3939	1369	117	10.5	50.1
		Percent	3.8	0.7	2.7	22	1.4
	Revised	GSE	364	14.4	20.1	1.69	1.44
		Total	4153	1374	134	9.87	50.3
		Percent	8.8	1.1	15	17	2.8
		GSE_R/GSE_O	2.4	1.5	6.4	0.72	2.0

[a] Units: metric tons
[b] Percent: GSE ÷ total x 100
[c] GSE_R/GSE_O: Revised GSE ÷ Original GSE

SECTION V

CONCLUSIONS

In the present study, a GSE survey form was designed to identify GSE and GSE operations data for various aircraft currently in use by the Air Force. The GSE operations data received from selected Air Force bases in response to an Air Force-conducted survey were compiled and analyzed. Air pollution emissions factors for the identified GSE were determined. The SIP was implemented and GSE operations data and emissions factors were incorporated into the SIP. A routine was developed to display GSE operations data and to compute GSE emissions for each aircraft type. For three Air Force bases, predictions of the SIP with the original GSE routine were compared to those of the SIP with the revised GSE routine. For each pollutant, except particulate matter, the revised routine predicted higher emissions than the original routine. This behavior was, to a large extent, a reflection of the new emissions factors used in the revised routine.

The net result of this study was the development of a more accurate computer emission inventory routine for GSE and its incorporation into the SIP. This has resulted in the SIP requiring more readily available data as input and in a simplification of manual data collection required at the individual base level.

SECTION VI

RECOMMENDATIONS

Based on limited experience with the revised GSE routine, it appears that it should be used in future applications of AQAM. Final judgment, however, must be reserved until an actual airbase assessment is undertaken with the new approach.

In developing this revised routine, several facts of peripheral nature became apparent. First, the data bases in the model concerning aircraft and aircraft engines could profit from updating. Second, the Source Inventory Program, even with the indicated restructuring, can be accommodated only on a large mainframe computer. With further restructuring, it is believed that a version capable of running on a modest minicomputer is possible. Such a feature might be desirable either to enable airbases to perform a source inventory locally or to allow data gatherers to perform validation inventories in the field.

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2. R. R. Sears, Air Pollutant Emission Factors for Military and Civil Aircraft, US EPA Publication EPA-450/3-78-117, 1978.

3. Draft Air Quality Assessment Model Data Collection Guide, Air Force Civil Engineering Center, Tyndall Air Force Base, Florida, 32403, 1976.

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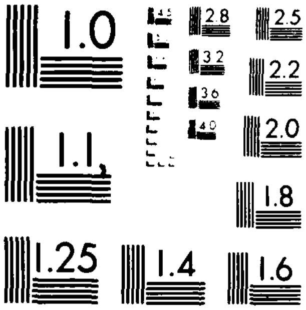

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ERRATA - AUGUST 1983

The following corrections are applicable to ESL-TR-81-60, "Development of a Computer Emission Inventory Routine for Aircraft Ground Support Equipment," Volume I, September 1981.

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Equations #6 and #7 should be changed to read as follows:

Equation #6:

$$\gamma_{\text{heater}} \quad \frac{[40 - \bar{T} + \Delta\bar{T}/2]^2}{2[\Delta\bar{T}/2]^2} \qquad \text{unless if } 40 - \bar{T} + \Delta\bar{T}/2 \leq 0 \text{ then } \gamma = 0.$$

Equation #7:

$$\gamma_{\text{cooler}} \quad \frac{[\bar{T} + \Delta\bar{T}/2 - 80]^2}{2[\Delta\bar{T}/2]^2} \qquad \text{unless if } \bar{T} + \Delta\bar{T}/2 - 80 \leq 0 \text{ then } \gamma = 0.$$

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