San Joaquin Valley
AIR POLLUTION CONTROL DISTRICT

2007 Area Source Emissions Inventory Methodology
810 – PISTON AIRCRAFT – MILITARY
810 – JET AIRCRAFT – MILITARY

I. Purpose

This document describes the Area Source Methodology used to estimate emissions of carbon monoxide (CO), nitrogen oxides (NO_x), fine particulate matter less than 10 microns (PM_{10}), volatile organic compounds (VOC), and sulfur oxides (SO_x), from military jet and piston aircraft in the San Joaquin Valley Air Basin. An area source category is a collection of similar emission units within a geographic area (i.e., a County). An area source category collectively represent individual sources that are small and numerous and that may not have been inventoried as specific point, mobile, or biogenic sources. The California Air Resources Board (CARB) has grouped these individual sources with other like sources into area source categories. These source categories are grouped in such a way that they can be estimated collectively using one methodology.

II. Applicability

The emission calculations from this Area Source Methodology apply to facilities that are identified by the following Category of Emission Source (CES) code and Reconciliation Emission Inventory Code (REIC):

Table 1. Emission inventory codes.

CES	REIC	Description
57323	810-800-1140-0000	Piston Aircraft - Military
47571	810-808-1400-0000	Jet Aircraft - Military

III. Point Source Reconciliation

Emissions from the area source inventory and point source inventory are reconciled against each other to prevent double counting. This is done using relationships created by the California Air Resources Board (CARB) between the area source REIC and the point sources' Standard Industry Classification (SIC) code and emissions process Source Category Code (SCC) combinations. The area sources in this methodology are not represented within the District's point source inventory so reconciliation is not necessary.

IV. Methodology Description

This methodology estimates mobile source emissions from the operation of military piston and jet aircraft within the San Joaquin Valley Air Basin's atmospheric mixing zone. This methodology does not include emissions from off wing engine tests (testing of engines in test cells) or auxiliary power units (APU) that are not mounted on the aircraft. Test cell emissions are included in the District's point source inventory and are considered a stationary source. Auxiliary power units are included in the statewide off-road equipment inventory as part of the airport ground support equipment.

Military aircraft operated by the Department of Defense include a wide variety of types ranging from jets to large transports to small piston engine aircraft and helicopters. Most military aircraft operations occur at military bases, but some occur at civilian airports. Examples of military operations that may operate out of civilian airports would be those of the National Guard. Therefore, the emissions from military aircraft will include operations from both military and civilian facilities.

Preparing an emissions inventory for military aircraft focuses on the emission characteristics of this source relative to the vertical column of air that ultimately affects ground level pollutant concentrations. This portion of the atmosphere, which begins at the earth's surface and is simulated in air quality models, is often referred to as the mixing zone. For the purposes of this methodology the mixing zone extends from the surface to a mixing height of 3,000 feet. The aircraft operations of interest within this layer are defined as the landing and takeoff (LTO) cycle. Each LTO cycle is comprised of several modes characterized by different times in cycle and different rates of fuel consumption The cycle begins when the aircraft approaches the airport on its descent from cruising altitude, lands, and taxis to the gate. It continues as the aircraft starts back up, taxis back out to the runway for subsequent takeoff and climbout as it heads back up to cruising altitude. Typical modes in a military LTO cycle are as follows:

- Aircraft approach. The time from which the aircraft enters the atmospheric mixing zone until it lands.
- Taxi/idle-in. The time spent from landing until the aircraft is turned off.
- Startup. Starting the aircraft engines back up.
- Taxi/idle-out. The time from engine startup until takeoff.
- Takeoff. The full throttle departure and ascent of the aircraft to an altitude of 500 to 1000 feet.
- Climbout. The ascent of the aircraft following takeoff until it passes out of the mixing zone.

In addition to the standard modes of the LTO cycle, military aircraft also perform specialized operations within the atmospheric mixing zone. These may include the following operations:

- Touch-and-goes (TGOs). This is the same as a standard LTO except they do not include taxi/idle-in or taxi/idle out modes
- Low fly bys (LFBs)/ Low flight patterns (LFP). These are aircraft flight patterns which occur below 3,000 feet in altitude and typically involve a constant power setting.
- On wing engine test. These are tests of engine operation with the engine still attached to the aircraft. These tests simulate flight operations at different power settings.

Aircraft engines can be operated at different power settings such as the following:

- Idle (all planes)
- Approach (all planes)
- Intermediate (all planes)
- Military (all planes and helicopters)
- Afterburner (jets)
- Ground Idle (helicopters)
- Flight Idle (helicopters)
- Normal (helicopters)
- Overspeed (helicopters)

The military services have developed fuel flow rates and emission factors for common power settings for the engines they use. To estimate emissions, they associate an aircraft's modes of operation with the time spent in that mode and the power setting typical of that mode.

Emissions at Military Bases.

Lemoore Naval Air Station, Fresno Air National Guard, and Fresno Army Helicopter Repair Depot were asked to provide their emissions from the operation of jet and piston aircraft. Since aircraft specific activity is considered to be sensitive information, only the emissions associated with the aircraft were requested. To assist with these emission estimates, the District provided to each military establishment an Excel spreadsheet embedded with sample calculations along with a data bank of common military aircraft and their associated modes of operation, power settings, fuel flow rates, times in mode, and emission factors.

Emissions at Other Airports.

LTO data was gathered for military aircraft activity at commercial airports. Emissions were calculated from this LTO data and emission factors.

V. Activity Data

Military Bases.

Aircraft specific activity of military aircraft at air bases is considered sensitive information, therefore only the emissions were reported to the District.

Other Airports.

LTO data of military aircraft was obtained from the FAA's Terminal Area Forecasts (TAF) and Form 5010 databanks (FAA, 2013a; FAA, 2013b). These sources provide LTO estimates for general aviation airports (see Appendix B for a summary of this data). Because the aircraft make and models were not available, the District assumed that all activity was associated with turbine-driven aircraft.

VI. Emission Factors

Military Bases.

Military airbases maintain flight records with detailed aircraft-specific activity data. This enables estimation of emissions using aircraft specific emission factors and the times in operational modes. Emission factors for military aircraft engines are categorized by five different power settings (fuel flow rates) which are related to modes of operation. Common power settings include: Idle, Approach, Intermediate, Military, and Afterburner. Helicopters are typically operated at Ground Idle, Flight Idle, Normal, Military, and occasionally over speed. The fuel flow rates utilized for emission calculations are typically in pounds of fuel burned per hour (lb/hr) specific to the operation mode and the emission rates for the pollutants of interest are in pounds of pollutant per one thousand pounds of fuel burned (lbs/1,000 lbs of fuel). However units of fuel flow rates and pollutant emission rates may differ from one military operation to another. The following table shows an example of different emission factors for a F-16 C/D jet aircraft.

Table 2. Emission Factors for a F-16 C/D Model F100-PW-229 *(United State Air Force IERA (2003)).*

Operation Type	Operation Mode	Power Setting	Fuel Flow Rate (lbs/hr)	Time in Mode (mins)	Emission Rate (lbs/1000lbs)				
					NOx	CO	VOC	PM10	SOX
Standard LTO	Approach	Approach	3,098	3.0	15.08	1.17	0.21	2.63	0.84
	Taxi/idle-in	Idle	1,087	10.0	3.8	10.16	0.38	2.06	0.84
	Taxi/idle-out	Idle	1,087	30.0	3.8	10.16	0.38	2.06	0.84
	Takeoff	Military	11,490	1.0	57.65	0.66	0.54	1.33	0.84
		Afterburner	20,793	1.0	50.92	76.62	16.26	1.15	0.84
	Climbout	Intermediate	5,838	0.5	17.53	0.15	0.3	2.06	0.84
TGO/LFB	Approach	Approach	3,098	3.0	15.08	1.17	0.21	2.63	0.84
	Takeoff	Military	11,490	1.0	57.65	0.66	0.54	1.33	0.84
		Afterburner	20,793	1.0	50.92	76.62	16.26	1.15	0.84
	Climbout	Intermediate	5,838	0.5	17.53	0.15	0.3	2.06	0.84
LFP	Approach	Approach	3,098	3.0	15.08	1.17	0.21	2.63	0.84
Testing	Approach	Approach	3,098	15.0	15.08	1.17	0.21	2.63	0.84
	Idle	Idle	1,087	15.0	3.8	10.16	0.38	2.06	0.84
	Military	Military	11,490	15.0	57.65	0.66	0.54	1.33	0.84
	Afterburner	Afterburner	20,793	15.0	50.92	76.62	16.26	1.15	0.84
	Intermediate	Intermediate	5,838	15.0	17.53	0.15	0.3	2.06	0.84

Other Airports.

In general, neither the FAA nor airport traffic control towers track operations by aircraft model for aircraft other than large commercial carriers. Because of this, detailed emission factors by engine type cannot be used to estimate emissions from these aircraft. Instead, the fleet-average emission factors listed in the table below were applied. These emission factors are used by EPA in the development of the National Emissions Inventory and are described in the documentation for aircraft activity (Eastern Research Group, 2011). They may be used as conservative emission factors for all aircraft with known LTO data but without a known make, model, and/or engine type.

Table 3. Fleet-average aircraft emission factors.

Aircraft Type	Emission Factor (tons/LTO)					
	NOx	CO	SOx	VOC	PM_{10}	$PM_{2.5}$
Commercial Aircraft	9.29E-03	1.12E-02	8.91E-04	2.93E-03	5.39E-04	5.26E-04
Air Taxi - Jet	3.88E-04	1.81E-03	8.12E-05	5.03E-04	3.02E-04	3.92E-05
Air Taxi - Piston	7.90E-05	1.41E-02	7.50E-06	8.48E-05	3.02E-04	3.92E-05
General Aviation - Jet	1.62E-04	4.79E-03	3.68E-05	2.73E-04	1.18E-04	1.54E-05
General Aviation - Piston	3.25E-05	6.01E-03	5.00E-06	7.52E-05	1.18E-04	1.54E-05
Military	7.90E-05	1.41E-02	7.50E-06	6.82E-04	3.02E-04	3.92E-05

VII. Emissions Calculations

Emissions calculations from LTO operations are based on flight operation type, aircraft type, engine model, the amount of time spent in each operational mode, fuel flow rate per operational mode, the pollutant emission rate associated with each fuel flow rate, and the number of LTO's or tests conducted for the year. The District assumes an average atmospheric mixing height of up to an altitude of 3,000 feet. Sample calculations can be found in Appendix A of this document.

VIII. Temporal Variation

A. Daily

CARB Code 24. 24 hours per day - uniform activity during the day.

B. Weekly

CARB Code 7. 7 days per week - uniform activity every day of the week.

C. Monthly

Monthly activity is assumed to be uniform for all military aircraft operations.

IX. Spatial Variation

Latitude and longitude coordinates for each airport included in this emissions estimate are provided in Appendix B. Emissions can be assigned to grid cells containing an airport having military aircraft activity. Vertically, aircraft emissions can be dispersed uniformly between the ground and a mixing height of 3,000 feet.

X. Growth Factor

Growth factors are developed by either the District's Strategies and Incentives Department or CARB for each EIC. These factors are used to estimate emissions in future years. The growth factors associated with this emissions category may be obtained from the District's Strategies and Incentives Department.

XI. Control Level

Control levels are developed by either the District's Strategies and Incentives Department or CARB for each EIC. Control levels are used to estimate emissions reductions in future years due to implementation of District rules. These control levels take into account the effect of control technology, compliance and exemptions at full implementation of the rules.

Military Aircraft operations are not subject to District rules. Control levels associated with this emissions category may be obtained from the District's Strategy and Incentives Department.

XII. CARB Chemical Speciation

CARB has developed organic gas profiles in order to calculate reactive organic gasses (ROG), volatile organic compounds (VOC) or total organic gasses (TOG) given any one of the three values. For each speciation profile, the fraction of TOG that is ROG and VOC is given. The organic gas profile codes can also be used to look up associated toxic compounds. CARB's speciation profiles for military aircraft emissions are presented in Table 4. Organic gas profile #586 is applied to REIC 810-808-1400-0000 (Jet Aircraft - Military) and organic gas profile #413 is applied to REIC 810-800-1140-0000 (Piston Aircraft - Military).

Table 4. CARB organic gas speciation profiles for commercial and civil jet and piston aircraft emissions.

Profile Description	CARB Organic Gas Profile#	Fractions	
		ROG	VOC
Composite Jet Exhaust JP5 (EPA 1097-1099)	586	0.892	0.892
Gasoline Non-Cat FTP Composite ARB IUS Summer 1994	413	0.885	0.885

CARB has developed particulate matter speciation profiles in order to calculate particulate matter (PM), particulate matter with a diameter less than or equal to 10 microns (PM_{10}) or particulate matter with a diameter less than or equal to 2.5 microns ($PM_{2.5}$) given any one of the three values. For each speciation profile, the fraction of PM that is PM_{10} and $PM_{2.5}$ is given. The particulate matter profile codes can also be used to lookup associated toxic compounds. CARB's speciation profiles for military aircraft emissions are presented in Table 5. Particulate matter profile #141 is applied to REICs 810-808-1400-0000 (Jet Aircraft - Military) and particulate matter profile #399 is applied to REICs 810-800-1140-0000 (Piston Aircraft - Military).

Table 5. CARB particulate matter speciation profiles for commercial and civil jet and piston aircraft emissions.

Profile Description	CARB PM Profile#	Fractions	
		PM_{10}	$PM_{2.5}$
Aircraft Jet Fuel	141	0.976	0.967
Gasoline Vehicles No Catalyst	399	0.90	0.68

XIII. Assessment Of Methodology

Emissions from military bases have been estimated via a “bottom-up” approach. The District requested military establishments in the San Joaquin Valley to report their emissions from jet and piston aircraft. Military aircraft activity rates are considered sensitive information. Therefore, only the total emissions by aircraft type (jet/piston) were reported to the District. The quality and accuracy of this estimate is subject to the accuracy of the data set reported to the District.

Estimates of emissions from military aircraft at non-base airports relied on activity estimates from the FAA and used fleet-average emission factors. These estimates could be improved with aircraft specific flight information.

Finally, military aircraft emissions could be reported as point sources to improve spatial resolution. Currently, the county level area source estimates are disaggregated using spatial surrogates.

XIV. Emissions

Following is the 2007 area source emissions inventory for REIC 810-808-1400-0000 and REIC 810-800-1400-0000 estimated by this methodology. No military piston aircraft were reported to be operated in the San Joaquin Valley Air District, so this methodology will not include emissions from these types of aircraft. Emissions are reported for each county in the District.

Table 6. Area source emissions for military jet and piston aircraft in 2007.

County	Emissions (tons/year)					
	NOx	CO	SOx	VOC[(1)]	PM_{10}	$PM_{2.5}$[(2)]
Jet Aircraft – Military 810-808-1400-0000						
Fresno	157.46	22.57	5.48	12.49	8.97	N/A
Kern	0.04	6.57	0.00	0.32	0.14	N/A
Kings	557.60	3717.10	22.90	1045.90	388.20	N/A
Madera	0.00	0.70	0.00	0.03	0.02	N/A
Merced	0.05	8.58	0.00	0.42	0.18	N/A
San Joaquin	0.12	20.84	0.01	1.01	0.45	N/A
Stanislaus	0.01	1.83	0.00	0.09	0.04	N/A
Tulare	0.01	1.76	0.00	0.09	0.04	N/A
TOTAL	715.29	3779.95	28.39	1060.35	398.04	N/A
Piston Aircraft – Military 810-800-1400-0000						
Fresno	0.00	0.00	0.00	0.00	0.00	N/A
Kern	0.00	0.00	0.00	0.00	0.00	N/A
Kings	0.00	0.00	0.00	0.00	0.00	N/A
Madera	0.00	0.00	0.00	0.00	0.00	N/A
Merced	0.00	0.00	0.00	0.00	0.00	N/A
San Joaquin	0.00	0.00	0.00	0.00	0.00	N/A
Stanislaus	0.00	0.00	0.00	0.00	0.00	N/A
Tulare	0.00	0.00	0.00	0.00	0.00	N/A
TOTAL	0.00	0.00	0.00	0.00	0.00	N/A

(1) The District only reports ROG to CARB. As noted in Section XII, ROG is the same as VOC.
(2) At this time, the District does not calculate $PM_{2.5}$ emissions. $PM_{2.5}$ emissions can be estimated using the speciation profiles found in Section XII.

Following is the net change in area source emissions between this update (2007 inventory year) and the previous (2006 CEIDARS inventory year) REIC 810-808-1400-0000 and REIC 810-800-1400-0000. The change in emissions are reported for each county in the District.

Table 7. Net change in emissions for military jet and piston aircraft in 2007-2006.

County	Emissions (tons/year)					
	NOx	CO	SOx	VOC[1]	PM_{10}	$PM_{2.5}$[2]
Jet Aircraft – Military 810-808-1400-0000						
Fresno	96.26	-244.23	-2.92	-135.96	-4.50	N/A
Kern	-21.96	-169.13	-3.30	-136.62	-28.85	N/A
Kings	-105.04	-1,140.91	-2.86	-168.15	-49.70	N/A
Madera	0.00	0.70	0.00	0.03	0.02	N/A
Merced	0.05	8.58	0.00	0.42	0.18	N/A
San Joaquin	-56.38	-117.26	-6.89	-79.73	-2.28	N/A
Stanislaus	-70.09	-318.67	-16.10	-187.88	-6.40	N/A
Tulare	0.01	1.76	0.00	0.09	0.04	N/A
TOTAL	-157.15	-1,979.16	-32.07	-707.8	-91.49	N/A
Piston Aircraft – Military 810-800-1400-0000						
Fresno	0.00	0.00	0.00	0.00	0.00	N/A
Kern	0.00	-1.41	0.00	0.00	0.00	N/A
Kings	0.00	0.00	0.00	0.00	0.00	N/A
Madera	0.00	0.00	0.00	0.00	0.00	N/A
Merced	0.00	0.00	0.00	0.00	0.00	N/A
San Joaquin	-0.90	-92.46	-0.60	-10.49	-0.99	N/A
Stanislaus	0.00	0.00	0.00	0.00	0.00	N/A
Tulare	0.00	0.00	0.00	0.00	0.00	N/A
TOTAL	-0.90	-93.87	-0.60	-10.49	-0.99	N/A

(1) The District only reports ROG to CARB. As noted in Section XII, ROG is the same as VOC.

(2) At this time, the District does not calculate $PM_{2.5}$ emissions. $PM_{2.5}$ emissions can be estimated using the speciation profiles found in Section XII.

XV. Revision History

2013. Revised to include non-base military aircraft emissions.

2007. This is a new District methodology.

XVI. Update Schedule

Emissions estimates for these source categories will be updated as needed by the District for planning purposes.

XVII. References

1. Eastern Research Group. 2011. Documentation for aircraft component of the national emissions inventory methodology. Report prepared for the U.S. Environmental Protection Agency under Contract No. EP-D-07-097. 63 pages.

2. Federal Aviation Administration. 2013a. Airport master record Form 5010 database. Accessed online on 9/25/2013 at http://www.faa.gov/airports/airport_safety/airportdata_5010/

3. Federal Aviation Administration. 2013b. Terminal area forecast. Accessed online on 9/25/2013 at http://aspm.faa.gov/main/taf.asp

4. United States Environmental Protection Agency (2002). Procedures for emission inventory preparation, Volume IV: Mobile sources. EPA420-R-92-009.

5. United States Environmental Protection Agency (2002). Procedures for emission inventory preparation volume IV: Mobile sources. Emission Planning and Strategies Division, Office of Mobile Sources and Technical Support Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. 227 pages.

6. United State Air Force IERA (2003). Air Emissions Inventory Guidance Document for Mobile Sources at Air Force Installations. Air Force Institute for Environment, Safety and Occupational Health Risk Analysis. IER-Rs-BR-SR-2001-0010.

7. Aircraft Environmental Support Office Naval Air Depot – North Island Code 08212, Building 810 P.O. Box 357058 San Diego, CA 92135-7058 (619)545-2914

XVIII. Appendices

Appendix A. Sample Calculations

Appendix B. Airports in the District with Military Aircraft Activity

Appendix A. Sample Calculations

A. Given the following:

Aircraft Model:	F-16 C/D
Engine Model:	F100-PW-229
Number of Engines:	2
LTO's for 2007:	1100

Operation Type	Operation Mode	Power Setting	Fuel Flow Rate (lbs/hr)	Time in Mode (mins)	Emission Rate (lbs NOx/1000 lbs fuel)
Standard LTO	Approach	Approach	3,098	3.0	15.08
	Taxi/idle-in	Idle	1,087	10.0	3.8
	Taxi/idle-out	Idle	1,087	30.0	3.8
	Takeoff	Military	11,490	1.0	57.65
		Afterburner	20,793	1.0	50.92
	Climbout	Intermediate	5,838	0.5	17.53

B. Example: Estimate the total NOx emissions for LTO operations of an F-16 C/D fighter jet in 2007

Power Setting	Num of Engines	x	2007 LTO	x	Time In Mode (mins)	/	Convert to hrs	x	Fuel Rate (lbs fuel/hr)	/	Convert to 1000's lbs fuel	x	Emission Factor (lbs NOx/ 1000 lbs fuel)	/	Convert to tons/yr	=	tons/yr
Approach	2	x	1100	x	3.0	/	60	x	3,098	/	1000	x	15.08	/	2000	=	2.57
Idle	2	x	1100	x	10.0	/	60	x	1,087	/	1000	x	3.8	/	2000	=	0.76
Idle	2	x	1100	x	30.0	/	60	x	1,087	/	1000	x	3.8	/	2000	=	2.27
Military	2	x	700	x	1.0	/	60	x	11,490	/	1000	x	57.65	/	2000	=	7.73
Afterburner	2	x	400	x	1.0	/	60	x	20,793	/	1000	x	50.92	/	2000	=	7.06
Intermediate	2	x	1100	x	0.5	/	60	x	5,838	/	1000	x	17.53	/	2000	=	0.94
															Total NOx Emissions		21.33

Appendix B. Airports in the District with Military Aircraft Activity

Table 8. Airports located within the San Joaquin Valley Air Pollution Control District for which landing and takeoff (LTO) data could be obtained for 2007.

Airport Name	City	Location ID	Latitude	Longitude	Terminal Area Forecast Military Aircraft LTOs[1]
Fresno County					
Fresno Yosemite Intl	Fresno	FAT	36-46-35.6000N	119-43-07.8000W	Survey[2]
Kern County					
Meadows Field	Bakersfield	BFL	35-26-01.9000N	119-03-27.6000W	467
Kings County					
NAS Lemoore	Lemoore	KNLC	36-19-58.8400N	119-57-07.4900W	Survey[2]
Madera County					
Madera Muni	Madera	MAE	36-59-19.0000N	120-06-44.8000W	50
Merced County					
Castle	Atwater	MER	37-22-49.7000N	120-34-05.5000W	510
Merced Rgnl//Macready Field	Merced	MCE	37-17-05.1000N	120-30-50.1000W	100
San Joaquin County					
Stockton Metropolitan	Stockton	SCK	37-53-39.0000N	121-14-17.9000W	1,481
Stanislaus County					
Modesto City/Harry Sham Fld	Modesto	MOD	37-37-33.0000N	120-57-15.9000W	130
Tulare County					
Visalia Muni	Visalia	VIS	36-19-07.1000N	119-23-34.3000W	100

[1]The Terminal Area Forecasts report s airport operations, which equals the sum of the number of landings and takeoffs. This value is divided by two to get the number of LTOs. Form 5010 also reports military aircraft operations as itinerant and local. These numbers are combined in this table.

[2]Aircraft emissions provides by the military operations at this location. LTO data not used for emissions estimates.