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Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling

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Purpose

EPA's NONROAD model computes emission inventories for nonroad engines. This report documents the default input values of median life, annual activity, and load factor for various types of nonroad engines. These values are used to calculate the fleet age distributions for each engine type included in this model. Annual activity and load factor values are also used to calculate the yearly emissions for each engine type included in the model.

Introduction

This report documents the default annual activity and load factor values. These estimates are used to determine emissions from engines by using the following equation. The discussion of the other default values of population, power, and emission factors are the subject of other reports.

$$Emissions = (Pop)\,(Power)\,(LF)\,(A)\,(EF)$$

where *Pop* = *Engine Population*
Power = *Average Power (hp)*
LF = *Load Factor (fraction of available power)*
A = *Activity (hrs/yr)*
EF = *Emission Factor (g/hp-hr)*

This report also documents the default values for the median life of engines. The first step in developing the age distribution is the determination of how long an engine is used in years. The median life, annual activity, and load factor are all variables used in estimating the median lifetime of nonroad engine. The median lifetime in years is determined from the median life expressed in units of hours at full load, the annual activity expressed in units of hours per year, and the load factor expressed in units of the fraction of available power as shown in the equation below.

$$\textit{Median Lifetime}\ (\textit{years}) = \frac{\textit{Median Life}\ (\textit{hrs})}{\textit{Activity}\ (\textit{hrs/yr}) * \textit{Load Factor}}$$

The fleet of engines' age distribution and scrappage rates are estimated as functions of the engine age expressed in the fraction of median lifetime. For instance, when engines of a given model year are used to their median lifetime, 50% of the engines sold in that model year have been scrapped and are not in use. In order to determine the engine population at any given in-use year, the number of engines in every model year remaining in service needs to be calculated based on the estimated median lifetime in years calculated with the equation above. A further discussion of how the age distributions and scrappage rates are used to incorporate fleet turnover is the subject of another report. (1)

For most applications, equipment is used until the engine no longer works; that is, median *engine* life is considered synonymous with median *equipment* life. Marine vessels and other large equipment such as mining and construction applications are exceptions to this rule, because they typically use replacement engines when the original engine cannot be rebuilt instead of purchasing entirely new equipment. Installing a new engine is assumed to have the same effect on emissions as replacing the equipment, so engine life remains the relevant value for age determination for these applications.

<u>Values Used in NONROAD for Median Life, Annual Activity, and Load Factor</u>

The estimates for median life, activity, and load factor used as default data files in NONROAD are described in this work. The NONROAD model classifies engine applications and fuel types with the use of a source categorization code (SCC). The descriptions shown in the tables below were translated to SCC's by the fuel type and application description. For diesel and gasoline engines, this translation is straightforward because the structure of the SCC's differentiates engines by fuel type. For application-specific engines, the description of the application is used to determine the appropriate SCC. The translation procedure of using application description and fuel type to denote SCC's is also described in the report describing default equipment populations. (2)

Median Life in Hours at Full Load

Engine life varies with engine type and power level. The NONROAD model uses the median life estimates that the California Air Resources Board in its OFFROAD model uses. (3) These estimates are listed by horsepower class and engine type in Table 1. The horsepower classes are defined in Table 2.

Liquid petroleum gas (LPG) and compressed natural gas (CNG) engines are primarily four-stroke spark-ignition engines and hence have many similarities with four-stroke gasoline engines. Because LPG and CNG engines are similar in design to gasoline engines, their median life is likely to be similar to the median life of gasoline engines. For this reason and the lack of relevant data to the contrary, LPG and CNG engines are assumed to have the same median life as gasoline engines in the NONROAD model.

The values described represent the only comprehensive review of the engine life associated with the engine type and power level available. They represent median values of engine life, not distinguishing the engine by make or model. Individual engine models may have longer or shorter median lives. Surveys of engine life by application or engine type are encouraged to improve the estimates shown below.

Table 1 Expected Engine Life in Hours at Full Load (3)

Engine Type	**HP 1**	**HP 2**	**HP 3**	**HP 4**	**HP 5**	**HP 6**	**HP 7**	**HP 8**	**HP 9**	**HP 10**
Diesel	1250	2500	2500	4000	4000	4000	6000	6000	6000	--
2-stroke Gasoline	150	200	750	--	--	--	--	--	--	--
4-stroke Gasoline	200	400	750	1500	3000	3000	3000	3000	3000	3000
CNG/ LPG	200	400	750	1500	3000	3000	3000	3000	3000	3000

Table 2 Horsepower Classes for Median Life (3)

HP Class	Diesel	2-stroke	4-stroke
HP 1	≤15	≤2	≤5
HP 2	16-25	3-15	6-15
HP 3	26-50	16-25	16-25
HP 4	51-120	26-50	26-50
HP 5	121-175	51-120	51-120
HP 6	176-250	121-175	121-175
HP 7	251-500	176-250	176-250
HP 8	501-750	251-500	251-500
HP 9	751+	501-750	501-750
HP 10	--	751+	751+

Small (<25 hp) Spark-Ignition Engine Median Life

The median life (the point where 50% of engines have been scrapped) for several applications of nonroad engines have been estimated previously in terms of years of use. (4) For the purpose of the NONROAD model, the median life was converted from units of years to units of hours at full load using load factors and median hours of use which are shown in Table 5 below. To do this, we used the second equation shown above. Median life in years from Table 3 was multiplied by hours per year and load factor given in Table 5 to create the column in Table 3 and used as an input to the NONROAD model.

The final values for the median life used in NONROAD for these selected applications are shown in Table 3. Lower or higher power level engines used the default values from ARB to distinguish power level among these applications because these engines are expected to be significantly different than the engines estimated previously.

Table 3: Median Life for the Bulk of Several Small Spark-Ignition Engine Applications

Application	Use	Power (min.)	Power (max.)	Median Life (Hours at Full Load)	Median Life (Years) (4)
Lawn Mowers	Residential	1	6	47.9	5.8
	Commercial	1	6	268	2

Trimmer/Edger/Cutter	Residential	0	3	19.4	4.3
	Commercial	0	3	157.6	2.3
Chainsaws	Residential	0	6	28	4.3
	Commercial	0	6	136.4	0.9
Leaf Blower\Vacuum	Residential	0	6	21.5	4.3
	Commercial	0	6	324.3	2.3
Tillers	Residential	0	11	39.4	5.8
	Commercial	0	11	830.7	4.4
Snowblowers	Residential	0	6	12.3	4.4
	Commercial	0	6	209.4	4.4
Commercial Turf	Commercial	3	25	988.9	2.9
Rear Engine Rider	Residential	3	16	79.3	5.8
	Commercial	6	16	627	2.9
Lawn and Garden Tractor	Residential	3	25	114.8	5.8
	Commercial	6	25	920	2.9

Activity in Hours per Year

The default input values for the activity estimates come from Power Systems Research (PSR), an independent research firm. This firm conducts several yearly surveys of equipment owners and determines a median usage rate for engines by application and fuel type. (5) These usage rates are shown in Table 4 for 2 and 4 stroke gasoline and diesel engines. The PSR methodology is described and evaluated in a report by Pechan. (6)

The PSR data represents the most comprehensive review of application specific activity available to the NONROAD team. It may be possible to determine activity regionally for a few specific types of nonroad equipment, and the results compared with the PSR estimates used in NONROAD. If such information becomes available, the Nonroad Engine Emissions Modeling Team would consider using such information in future versions of the model.

No data exist regarding activity levels for LPG and CNG engines. These engines are similar to gasoline engines because they employ spark-ignition. Therefore, LPG and CNG engines are more likely to be used in applications where gasoline engines are used, so they are assumed to have the same usage pattern as gasoline engines.

Load Factor

PSR also estimates the load factor from surveys of equipment users. PSR calculates the fraction of load from the estimate of hours of usage per year, the fuel consumption per year, and the fuel consumption rate at rated power for each engine in the field. A median fraction of available power is determined for specific applications. The load factors are also shown in Table 4. As was the case for activity levels, LPG and CNG engines are assigned the load factors for gasoline engines.

The load factor is determined from actual and maximum fuel consumption rates for various pieces of equipment. If alternative surveys become available, they would be considered for future versions. For reference, the PSR methodology is explained in detail in the Pechan report. (6)

Table 4: PSR Estimates of Activity and Load Factor for Gasoline and Diesel Engines*

PSR Application Description	SCC	Activity Diesel (Hrs/year)	Load Factor Diesel (% of Max. Power)	Activity Gasoline (Hrs/year)	Load Factor Gasoline (% of Max. Power)
Generator Sets	22xx006005	338	74	115	68
Air Compressors	22xx006015	815	48	484	56
Pumps	22xx006010	403	74	221	69
Oil Field Equipment	22xx010010	1231	92	1104	90
Underground Mine Equipment	22xx009010	1533	68	260	80
Refrigeration/AC	22xx003060	1341	28	605	46
Tactical Military Equipment	not modeled	260	62	225	68
Terminal Tractors	22xx003070	1257	82	827	78
Welders	22xx006025	643	45	208	51
Forklifts	22xx003020	1700	30	1800	30
Other Material Handling	22xx003050	421	59	386	53
Locomotive	not modeled	848	63	15	91
Scrubbers/Sweepers	22xx003030	1220	68	516	71
Surfacing Equipment	22xx002024	561	45	488	49
Forest Equipment	22xx007015	1276	71	35	70
Marine Auxiliary	not modeled	2608	67	175	61
Chippers/Grinders	22xx004066	465	73	488	78
Cranes	22xx002045	806	43	415	47
Excavators	22xx002036	859	57	378	53
Scrapers	22xx002018	914	72	540	70
Graders	22xx002048	821	61	504	64
Crawler Dozers	22xx002069	936	64	700	80
Rubber Tire Dozer	22xx002063	899	59	900	75
Rubber Tire Loader	22xx002060	761	68	512	71
Crush/Processing Equipment	22xx002054	955	78	241	85

Paving Equipment	22xx002021	622	53	175	59
Other Construction	22xx002081	606	62	371	48
Bore/Drill Rigs	22xx002033	466	75	107	79
Skid Steer Loader	22xx002072	818	55	310	58
Rollers	22xx002015	745	56	621	62
Off-Highway Truck	22xx002051	1641	57	450	80
Pavers	22xx002003	821	62	392	66
Trenchers	22xx002030	593	75	402	66
Tractor\Loader\Backhoe	22xx002066	1135	55	870	48
Irrigation Sets	22xx005060	749	65	716	60
Agricultural Tractor	22xx005015	475	70	550	62
Other Agricultural Equipment	22xx005055	381	51	124	55
Combines	22xx005020	150	70	125	74
Swathers	22xx005045	110	55	95	52
Balers	22xx005025	95	58	68	62
Powerboats (Inboard Marine) ****	2282010005 2282020005	200	35	100	38
Trimmer/Edger/Cutter**	22xx004025 22xx004026	60	43	34	68
Agricultural Mowers	22xx005030	363	43	175	48
Snowblower**	22xx004035 22xx004036	400	65	45	78
Cement/Material Mixers	22xx002042	275	56	84	59
Pressure Washer	22xx006030	145	30	115	85
Tillers**	22xx005040	172	78	43	71
Dumpers/Tenders	22xx002078	566	38	127	41
Plate Compactors	22xx002009	484	43	166	55
Specialty Vehicle/Carts	22xx001060	435	65	65	58
Lawn and Garden Tractor**	22xx004055 22xx004056	544	57	104	62
Aerial Lifts	22xx003010	384	46	361	46
Lawn Mowers**	22xx004010 22xx004011	320	55	76	70
Leaf Blower/Vacuum**	22xx004030 22xx004031	120	40	56	75
Commercial Turf Equipment**	22xx004071	1068	55	733	60
Off-Highway Tractors	22xx003070	855	65	155	70
Sprayers	22xx005035	90	58	80	65
Chainsaws**	2260004020 2260004021 2260007005	70	60	26	92
Snowmobiles**	22xx001020	50	40	121	81
Light Plants\Signal Boards	22xx002027	535	78	318	72
Other General Industrial	22xx003040	878	51	713	54

Wood Splitter	22xx004060 22xx004061	265	55	76	69
Other Lawn Garden**	22xx004075 22xx004076	433	65	61	58
Concrete/Ind. Saws	22xx002039	580	73	610	78
Sailboat Auxiliary***	22820xx020 22820xx025	68	32	62	35
Railway Maintenance	228500x015	943	47	184	62
Aircraft Support	22xx008005	732	51	681	56
Rear Engine Rider**	22xx004040	480	64	86	67
Rough Terrain Forklifts	22xx002057	662	60	413	63
Hydro Power Unit	22xx005050	790	48	450	56
Front Mowers	22xx004055 22xx004056	480	56	86	65
Gas Compressors	22xx006020	8500	60	8500	60
All-Terrain Vehicles\Off-road Motorcycles	22xx001030	0	0	135	72
Personal Water Craft****	2282005015	0	0	100	42
Mini-Bikes	22xx001040	0	0	55	62
Golf Carts	22xx001050	1150	49	1080	46
Tampers/Rammers	22xx002006	460	43	160	55
Shredders	22xx004050 22xx004051 22xx007010	120	40	50	80
Crawler Tractor (Agricultural Tractor with Crawler Tracks)	No population not used	936	64	700	80
2-Wheel Tractors	22xx005010	544	62	286	62
Outboard Engines****	2282005010 2282020010	150	29	100	32

* Gasoline values are used for LPG and CNG engines.
** See discussion below of **Small Spark-Ignition Engines** for alternate use and load factors.
*** Gasoline sailboat auxiliary is included in outboard and powerboats (inboard in the SCC nomenclature)
**** New values for gasoline recreational marine shown below

Small (<25 hp) Spark-Ignition Engines Activity and Load Factor

Regulations to be proposed for small spark-ignition engines are described in greater detail in another report (2), and the supporting documentation for those regulations include estimates of activity and load for a few important applications. (4) The activity and load factors and power levels for these applications, mainly lawn and garden equipment, were derived from data supplied during discussions regarding the proposed regulations. These alternate values are shown in Table 5 and represent a departure from the PSR values shown above. For applications not shown in Table 5, the PSR values were used because the PSR survey includes such categories as construction, agricultural, commercial, and many other engines applications already considered commercial and not included in the data submitted for the rulemaking.

Many of the small spark-ignited engines are used in lawn and garden equipment applications, and lawn and garden equipment is used both by commercial and residential users. The commercial users are grounds keepers for nonresidential, large apartment complexes, and some single-family homes. Commercial equipment therefore has significantly different usage in terms of hours per year and weekday and weekend day than residential equipment. To account for these differences in equipment usage, separate SCC's were defined to distinguish commercial from residential lawn and garden equipment.

Table 5: Usage and Load Factors for Several Small Spark-Ignition Engine Applications

Application	**Use**	**Annual Hours**	**Load Factor** (fraction of power)
Lawn Mowers	Residential	25	0.33
	Commercial	406	0.33
Trimmer/Edger/Cutter	Residential	9	0.50
	Commercial	137	0.50
Chainsaws	Residential	13	0.50
	Commercial	303	0.50
Leaf Blower\Vacuum	Residential	10	0.50
	Commercial	282	0.50
Tillers	Residential	17	0.40
	Commercial	472	0.40
Snowblowers	Residential	8	0.35
	Commercial	136	0.35
Commercial Turf	Commercial	682	0.50
Rear Engine Rider	Residential	36	0.38
	Commercial	569	0.38
Lawn and Garden Tractor	Residential	45	0.44
	Commercial	721	0.44

Recreational Marine Engines

As described in another report (2), recreational marine engines are divided into three applications; inboard, outboard, and personal watercraft. The outboard category includes the inboard\outboard sterndrive engines formerly considered as a separate application in the SCC system because the engine types are similar. The inboard engines are most closely associated with the PSR category ‘powerboats’ in Table 3. Personal watercraft were included in the PSR category formerly reserved for Off-Road Motorcycles which are now included with All Terrain Vehicles.

A study of recreational boating activity indicates that boating activity may be considerably different than PSR estimates. (5, 7) In order to determine and estimate for activity in hours per year, it was necessary to estimate the number of engines (E), yearly fuel consumption of the engines (FC), brake-specific fuel consumption (BSFC), average horsepower (Hp), and a load factor (LF) by type of engine as described in the equation below.

Activity (hrs/year) = (FC) / [(E) * (Hp) * (LF) * (BSFC)]

According to the report (7), the fuel consumption and number of boats by boat type were determined and given in Tables II-3 (page II-6) and II-8 for gasoline-fueled engines. Cabin cruisers and other cabin boats were assumed to be inboard gasoline. Personal watercraft were determined uniquely, and all other boats were assumed to be driven by outboard-style engines. The total number of inboard, outboard, and personal watercraft boats were estimated to be 998,000, 9,065,000, and 200,000 respectively. Table II-9 shows the fraction of boats that have one and two engines where 26.8% of inboard boats have two engines; 2.7% of outboard boats have two engines; and no personal watercraft engines. So it is estimated that there were 1,265,000 inboard, 9,309,755 outboard, and 200,000 personal watercraft engines nationally in 1990-1991, the time period for the survey.

Total fuel consumption was determined from Table II-3 based on the criteria described above to be 257,173,000 gallons for inboard, 672,009,000 gallons for outboard, and 25,063,000 for personal watercraft for the survey year.

To determine the fuel consumption of the engines, data was submitted to EPA which indicated fuel consumption as a function of power level and is shown in Table 6. (8) The fraction of engines by power level was determined from PSR data for the 1990 in-use year and associated with fuel consumption estimates to determine an average fuel consumption of 0.216 for outboard, 0.100 for inboard, and 0.160 for personal watercraft in units of gallons/hp-hr.

Table 6 Fuel Consumption by Power Level

Engine Type	Power Level	Fuel Consumption (gallons/hp-hr)
2-stroke	0-16 hp	0.27
	>16 hp	0.16
4-stroke	0-25 hp	0.14
	25-40 hp	0.12
	>40 hp	0.10

The average power for the three types of engines was determined from the PSR estimates of the 1990 in-use populations. Price Waterhouse estimate average power level by boat length and type of boat rather than a direct measure of average power level. The average power level of outboard engines was determined to be 37 horsepower from PSR compared with roughly 66 for the Price Waterhouse estimate. The average power level for inboard engines was estimated to be 166 from PSR compared with 179 for the Price Waterhouse. The average power level for personal watercraft was estimated to be 52 from PSR compared with 50 for Price Waterhouse. By using the PSR data for average power level, we are consistent with the use of PSR in determining the population distributions for this version of NONROAD.

Other supplied comments indicates that EPA should revise the load factor to accurately reflect the duty cycle in the certification test of 20.7% of rated power. In-use data of load factor is not available, and the PSR estimates of load factor (32% for outboard, 38% for inboard, and 42% for personal watercraft) are not currently documented.

Using the combined information and estimates, the average activity is estimated to be 75 hours per year for inboard, 45 hours per year for outboard, and 73 hours per year for personal watercraft engines compared with the PSR estimate of 100 hours for all types of recreational marine gasoline engines. It is helpful to remember that this implied activity is related to the number of hours that the engine actually operates, not necessarily how many hours the boat is in-use on the water.

References

(1) EPA, "Growth and Scrappage Methodology Report for NONROAD," NR-008, Jan. 1998.

(2) EPA, "Nonroad Engine Population Estimates," NONROAD Documentation, NR-006, Dec., 1997.

(3) ARB, "Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model," Energy and Environmental Analysis, Inc., February, 1997. Table 3-1.

(4) EPA, "Statement of Principles for Nonroad Phase 2 Small Spark-Ignited Engines; Proposed Rule," 62 FR 14740, March, 27, 1997.

(5) Power Systems Research, "Reference Guide, US Parts Link Edition 6.2," St.Paul, MN.

(6) E.H. Pechan, "Evaluation of Power Systems Research (PSR) Nonroad Population Data Base," prepared for Office of Mobile Sources, U.S. Environmental Protection Agency, September 1997, EPA Contract No. 68-D3-0035, Work Assignment No. III-107, Pechan Report No. 97.09.003/1807.

(7) Price Waterhouse, "National Recreational Boating Survey," Draft Final Report, Prepared for the U.S. Fish and Wildlife Service and the U.S. Coast Guard, March 9, 1992.

(8) Ted Morgan, "Emission Data for Recreational Marine Engines," communication to Ken Zerafa of the EPA, September 13, 1991.

(9) Ted Morgan, communication to Rich Wilcox of the EPA, April 13, 1998.