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United States
Environmental Protection
Agency

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# NR-011d

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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**Purpose**

This report addresses the emission deterioration rates for spark-ignition engines used in the final NONROAD2008a model. The specific deterioration inputs used in NONROAD and their basis will be addressed for land-based spark-ignition engines at or below 25 horsepower, land-based spark-ignition engines over 25 horsepower, recreational equipment, and recreational marine spark-ignition engines using gasoline. Deterioration is also addressed for land-based liquid petroleum gas (LPG) and compressed natural gas engines (CNG). Deterioration inputs for compression-ignition (diesel) engines are addressed in the report, Exhaust Emission Factors for Nonroad Engine Modeling - Compression Ignition (NR-009d). Relative to the December 2005 version of this report, this version has been updated to incorporate the deterioration rates corresponding to the Phase 3 exhaust standards in the 2008 final rulemaking affecting small nonroad nonhandheld SI engines and equipment, as well as the 2010 exhaust standards for marine SI engines and vessels. [1] It describes updates to the deterioration rates for nonhandheld Phase 2 engines. It also reflects new technology type names assigned to offroad motorcycles, all-terrain vehicles, and snowmobiles.

**Background**

As used here, the term *deterioration* refers to the degradation of an engine's exhaust emissions performance over its lifetime due to normal use or misuse (i.e., tampering or neglect). Engine deterioration increases exhaust emissions, usually leads to a loss of combustion efficiency, and can in some cases increase nonexhaust emissions. The amount of emissions increase depends on an engine's design, production quality, and technology type (e.g., spark ignition two-stroke and four-stroke, compression ignition). Other factors, such as the various equipment applications in which an engine is used, usage patterns, and how it is stored and maintained, may also affect deterioration.

The term *deterioration rate* refers to the degree to which an engine's emissions increase per unit of activity. Nonroad engine activity is expressed in terms of hours of use or fraction of median life. The term *deterioration factor* refers to the ratio of an engine's emissions at its median life divided by its emissions when new.

The terms *useful life* and *median life* are used in the following manner in this report in order to avoid confusion. *Useful life* is a regulatory term used to indicate the amount of time during the life of a nonroad engine that a manufacturer must certify to the U.S. EPA that the engine meets a required emission standard as defined by a regulation. *Median life,* as used in this report, refers to the age at which 50 percent of the engines sold in a given year have ceased to function and have been scrapped.[1]

## Core Challenge

The core challenge associated with estimating nonroad engine deterioration is the development of reasonably accurate deterioration rates for the enormous range of nonroad engine types and applications from the limited amount of nonroad emission deterioration data that exist at this time. To estimate deterioration, the emission performance of engines at various ages is required. Such information can be obtained from a longitudinal study that examines the same set of engines periodically as they age, or from a sampling study that tests engines of various ages but the same basic design. In either case, the engines studied should be selected randomly from the population of engines actually being used in the field.

Given the limited available test data, EPA is currently unable to develop unique deterioration rates based on actual engine test data for all applications and power levels covered by NONROAD. The Office of Transportation and Air Quality has conducted emissions testing on small spark ignition lawn & garden engines and large compression-ignition engines. The nonroad engine industry and a few States have also conducted some nonroad engine emissions testing. However, the nonroad engine emissions data currently available are still limited when compared to the large number of nonroad engine types and applications for which these engines are used, particularly for the purposes of evaluating emission deterioration as engines age. The EPA has obtained extensive data on the emissions deterioration of light-duty highway engines, but these engines are unlikely to deteriorate in a fashion typical of nonroad engines due to fundamental differences in engine and emission control technology design, maintenance, and operation.

A related challenge is that the EPA has essentially no data on the incidence of tampering and/or neglect of proper maintenance and only limited data that distinguish the effect of such malmaintenance from the effects of normal usage. These data are based on emission tests of two lawnmower engines that had various components, including the sparkplug, air filter, and oil, manipulated to simulate bad maintenance practices (i.e., not changing the sparkplug, air filter and oil on a regular basis, as recommended by the manufacturer). The results of this effort were inconclusive, suggesting that intentional disablement of engine components does not adequately simulate emissions deterioration from normal usage. The EPA requests that state and industry stakeholders share any data regarding the incidence of tampering and neglect of proper maintenance they may have. The EPA also requests that stakeholders share any data they have

[1] Median life is defined as the midpoint of the scrappage curve at which half of the engines in a given population cease to function and are scrapped. For more information, please refer to the technical report on activity, load factors and median life ( NR-005d) and the technical report about scrappage (NR-007c).

regarding the relationship between emissions deterioration due to normal usage and emissions deterioration due to intentional disablement of engine components.

**Method of Applying Deterioration In NONROAD**

Generally, the NONROAD model addresses the effects of deterioration in the inventory calculation by multiplying a zero hour emission factor for each category of engine by a deterioration rate as the engine ages. The following formula describes the basic form of the calculation:

$$EF_{aged} = EF_o * DF \qquad (1)$$

where: EF (aged) is the emission factor for an aged engine
$EF_o$ is the emission factor for a new engine
DF is the deterioration factor.

In order for the NONROAD model to be compatible with the EPA's small nonroad spark ignition engine rulemaking process and also be able to calculate deterioration for other engines, we have derived the following multi-purpose deterioration function:

$$DF = 1 + A * (\text{Age Factor})^b \quad \text{for Age Factor} \leq 1 \qquad (2)$$
$$DF = 1 + A \quad \text{for Age Factor} > 1$$

where Age Factor= $\dfrac{\text{[Cumulative Hours * Load Factor]}}{\text{Median Life at Full Load, in Hours}}$

A = DF Coefficient for a given technology type
b = Age Exponent for a given technology type; $b \leq 1$

The constants A and b can be varied to approximate a wide range of deterioration patterns. "A" can be varied to reflect differences in maximum deterioration. For example, setting A equal to 2.0 would result in emissions at the engine's median life being three times the emissions when new. The shape of the deterioration function is determined by the second constant, "b." This constant can be set at any level between zero and 1.0; currently, the NONROAD model sets "b" equal to either 0.5 or 1.0. The first case results in a curvilinear deterioration rate in which most of the deterioration occurs in the early part of an engine's life. The second case results in a linear deterioration pattern in which the rate of deterioration is constant throughout the median life of an engine.

The NONROAD model also contains values for a third constant, labeled "Emission Cap" or "Cap." When the Cap is equal to 1, deterioration is capped at the end of an engine's median life. When the Cap is equal to 2, deterioration is not capped. In NONROAD2005, deterioration was capped for all engines, but in NONROAD2008a, the cap was removed for all nonhandheld engines.

SI engines have a wide range of designs that affect their emissions deterioration. To model these different deterioration patterns, NONROAD categorizes SI engines into “technology types” by their design and emission control equipment. A given technology type can apply to one or more horsepower-application categories, and a given horsepower-application category can be divided into more than one technology type. NONROAD applies a given deterioration function (that is, a given A, b, and Cap value) to all engines of a given technology type, regardless of their application or power range. As a result, a single technology type may be applied to engines with very different median lives, but this difference is handled by expressing engine age in terms of the “Age Factor” defined above. The EPA believes this approach is reasonable, since deterioration patterns should be more closely related to the design of the engine and its emission control technology than to the kind of application in which it is used. Furthermore, the available data on emissions deterioration of nonroad SI engines is insufficient to develop separate deterioration functions for the many combinations of application, horsepower range, and technology type.

NONROAD’s technology type feature allows each horsepower-application category to be divided into as many as 15 technology types, each with its own deterioration pattern. The technology type feature gives the model flexibility to handle the full range of engine designs used in nonroad equipment. However, deterioration data for each technology type across different applications are not available at the present time. Thus, the NONROAD model does not apply different deterioration patterns to engines of the same technology type used in different applications. Instead, the model applies different deterioration patterns to engines within each engine type (i.e., two-stroke and four-stroke spark ignition) based on the more detailed engine classes defined in the rulemakings to date. [1,2,3,4,5,6] In other words, NONROAD models deterioration for tiller and lawn mower applications that are equipped with the same engine type by using the same deterioration pattern for that technology type.

## Deterioration Inputs For Land-based Engines At or Below 25 Horsepower

This category includes all engines ≤ 25 hp except those used for recreational applications (such as motorcycles or snowmobiles), for marine propulsion, or for toy boats and airplanes. The engines in this category are used primarily in lawn and garden equipment.

For this category, engines are segregated by the class of the engine (I - V). Each class is determined by the use of the engine, i.e., handheld or nonhandheld, and engine displacement. Classes I and II refer to nonhandheld small SI engines; classes III, IV, and V refer to handheld small SI engines. The classes have the following displacements: Class I (< 225cc); Class II (≥ 225cc); Class III (< 20cc); Class IV (≥ 20cc and < 50cc); Class V (≥ 50cc).

Engines in handheld applications (such as leafblowers and chainsaws) are subject to two phases of regulation (Phase 1 and Phase 2). Under the Phase 1 regulations, new engines have had to meet emission standards for HC, CO, and $NO_x$ since 1997. More stringent Phase 2 standards phase in between 2002 and 2007.

For nonhandheld applications (such as lawn and garden tractors and lawnmowers), similar Phase 1 regulations have been in place since 1997. More stringent Phase 2 standards phase in between 2001 and 2007. Phase 3 standards are phased in beginning in 2012 for Class I engines and 2011 for Class II engines. The test procedure used for the small SI regulations is the Small SI Engine Federal Steady-State Test Procedure.

Tables 1-5 contain the inputs for the deterioration function for these five classes of engines. There are no LPG or CNG engines less than 25 hp in final NONROAD2008a; therefore, the emission factors in these tables are used for gasoline engines in the model.

The constant ‘b’ is set at 0.5 for four-stroke engines, resulting in a square root relationship between age and deterioration. The constant ‘b’ is set at 1.0 for two-stroke engines, which produces a linear relationship between age and deterioration. The emission cap is set at 1 for handheld and 2 for nonhandheld engines.

For each pollutant and each engine type, variable ‘A’ represents the maximum deterioration rate reached at one median life. For the variable ‘A,’ EPA derived the deterioration values based on analyses done during the development of the various rules. The values were initially taken from the original Phase I Regulatory Support Document for maximum life emission factors and new engine emission factors. Based on later analysis done for the Phase 2 nonhandheld final rule, all small (and large) spark ignition engine NOx deterioration factors were changed to zero. Also as a result of that analysis, the HC deterioration values for handheld 2-stroke catalyst technology types (G2HxC2) were updated.

Since the release of NONROAD2005, Phase 3 standards have been finalized for small SI nonhandheld engines. Based on analyses done during rule development, updates were made to the Phase 2 deterioration rates for these engines, based on in-use testing data for 16 walk behind mowers. [7] In addition, Phase 3 deterioration rates were developed. [8]

It should be noted that particulate matter (PM) standards were not considered or included in rulemakings to date, and little data exists for PM deterioration rates. Based on EPA’s best judgment at this time, PM deterioration in two and four-stroke engines are equated to that of HC in the final NONROAD2008 model whenever data were lacking. The EPA requests stakeholders with information about the PM emissions deterioration of two-stroke engines to submit such data.

The deterioration rates used in NONROAD for small engines approximate the levels of deterioration found in testing, including the testing summarized in NEVES and the testing done to support the rules. Where these test results differ, the EPA has chosen to give greater weight to data taken from engines which have experienced usage patterns that reflect expected field conditions. The test data submitted to EPA for the Phase 2 Small Engine Rules, for example, reflects testing of engines that have undergone accelerated aging which EPA does not believe to be representative of the aging experienced by engines in use. The EPA believes that the deterioration rates used in NONROAD are more reflective of the deterioration rates that one would expect to find out in the field when equipment powered by small spark ignition engines is used by the average person.

Table 1
Class I (Displacement < 225 cc) Nonhandheld Deterioration Factors*

| Engine Tech Type | A | | | | | b | Cap |
|---|---|---|---|---|---|---|---|
| | **HC** | **CO** | **NOx** | **PM** | **BSFC** | | |
| G2N1 (gas 2-stroke nonhandheld Class I, baseline) | 0.201 | 0.199 | 0 | 0.201 | 0 | 1 | 2 |
| G4N1S (side-valve, 4-stroke, baseline) | 1.1 | 0.9 | 0 | 1.1 | 0 | 0.5 | 2 |
| G4N1O (overhead valve, 4-stroke, baseline) | 1.1 | 0.9 | 0 | 1.1 | 0 | 0.5 | 2 |
| G4N1S1 (Phase 1 side-valve, 4-stroke) | 5.103 | 1.109 | 0 | 5.103 | 0 | 0.5 | 2 |
| G4N1O1 (Phase 1 overhead valve, 4-stroke) | 1.753 | 1.051 | 0 | 1.753 | 0 | 0.5 | 2 |
| G4N1S2 (Phase 2 side-valve, 4-stroke) | 1.753 | 0.07 | 0.18 | 1.753 | 0 | 0.5 | 2 |
| G4N1O2 (Phase 2 overhead valve, 4-stroke) | 1.753 | 0.07 | 0.18 | 1.753 | 0 | 0.5 | 2 |
| G4N1S3 (Phase 3 side-valve, 4-stroke) | 0.797 | 0.07 | 0.302 | 1.753 | 0 | 0.5 | 2 |
| G4N1O3 (Phase 3 overhead valve, 4-stroke) | 0.797 | 0.07 | 0.302 | 1.753 | 0 | 0.5 | 2 |

* Assigned NONROAD hp range: 3-6 hp

Table 2
Class II (Displacement ≥225 cc) Nonhandheld Deterioration Factors*

| Engine Tech Type | A | | | | | b | Cap |
|---|---|---|---|---|---|---|---|
| | **HC** | **CO** | **NOx** | **PM** | **BSFC** | | |
| G2N2 (gas 2-stroke nonhandheld Class II, baseline) | 0.201 | 0.199 | 0 | 0.201 | 0 | 1 | 2 |
| G4N2S (side-valve, 4, baseline) | 1.1 | 0.9 | 0 | 1.1 | 0 | 0.5 | 2 |
| G4N2O (overhead valve, 4-stroke, baseline) | 1.1 | 0.9 | 0 | 1.1 | 0 | 0.5 | 2 |
| G4N2S1 (Phase 1 side-valve, 4-stroke) | 1.935 | 0.887 | 0 | 1.935 | 0 | 0.5 | 2 |
| G4N2O1 (Phase 1 overhead valve, 4-stroke) | 1.095 | 1.307 | 0 | 1.095 | 0 | 0.5 | 2 |
| G4N2O2 (Phase 2 overhead valve, 4-stroke) | 1.095 | 0.08 | 0 | 1.095 | 0 | 0.5 | 2 |
| G4N23a (Phase 3 overhead valve, 4-stroke) | 0.797 | 0.08 | 0.302 | 1.095 | 0 | 0.5 | 2 |

* Assigned NONROAD hp range: 6-25 hp

Table 3
Class III (Displacement < 20cc) Handheld Deterioration Factors*

| Engine Tech Type | A | | | | | b | Cap |
|---|---|---|---|---|---|---|---|
| | HC | CO | NOx | PM | BSFC | | |
| G2H3 (gas 2-stroke handheld Class III, baseline) | 0.2 | 0.2 | 0 | 0.2 | 0 | 1 | 1 |
| G2H31 (Phase 1) | 0.24 | 0.24 | 0 | 0.24 | 0 | 1 | 1 |
| G2H3C1 (Phase 1 with catalyst) | 0.24 | 0.24 | 0 | 0.24 | 0 | 1 | 1 |
| G2H3C2 (Phase 2 with catalysts) | 0.72 | 0.24 | 0 | 0.24 | 0 | 1 | 1 |

* Assigned NONROAD hp range: 0-1 hp

Table 4
Class IV (20cc ≤ Displacement < 50 cc) Handheld Deterioration Factors*

| Engine Tech Type | A | | | | | b | Cap |
|---|---|---|---|---|---|---|---|
| | HC | CO | NOx | PM | BSFC | | |
| G2H4 (gas 2-stroke handheld Class IV, baseline) | 0.2 | 0.2 | 0 | 0.2 | 0 | 1 | 1 |
| G2H41 (Phase 1) | 0.29 | 0.24 | 0 | 0.29 | 0 | 1 | 1 |
| G2H4C1 (Phase 1 with catalyst) | 0.29 | 0.24 | 0 | 0.29 | 0 | 1 | 1 |
| G4H41 (Phase 1 4-stroke) | 1.1 | 0.9 | 0 | 1.1 | 0 | 0.5 | 1 |
| G2H4C2 (Phase 2 with catalyst) | 0.77 | 0.24 | 0 | 0.29 | 0 | 1 | 1 |
| G4H42 (Phase 2 4-stroke) | 1.1 | 0.9 | 0 | 1.1 | 0 | 0.5 | 1 |

* Assigned NONROAD hp range: 1-3 hp

Table 5
Class V (Displacement ≥ 50cc) Handheld Deterioration Factors*

| Engine Tech Type | A | | | | | b | Cap |
|---|---|---|---|---|---|---|---|
| | HC | CO | NOx | PM | BSFC | | |
| G2H5 (gas 2-stroke handheld Class V, baseline) | 0.2 | 0.2 | 0 | 0.2 | 0 | 1 | 1 |
| G2H51 (Phase 1) | 0.266 | 0.231 | 0 | 0.266 | 0 | 1 | 1 |
| G2H5C1 (Phase 1 with catalyst) | 0.266 | 0.231 | 0 | 0.266 | 0 | 1 | 1 |
| G2H52 (Phase 2) | 0.266 | 0.231 | 0 | 0.266 | 0 | 1 | 1 |

* Assigned NONROAD hp range: 3-6 hp

**Deterioration Inputs for Land-based Spark Ignition Engines Greater than 25 Horsepower (19 kilowatts)**

The deterioration factors currently used in NONROAD for large spark-ignition engines over 25 horsepower found in industrial and commercial equipment (e.g., forklifts, generators, compressors) are based on those used in the final rulemaking for recreational equipment and large spark-ignition engines. [9] These are based on on-highway deterioration data. The deterioration factors for recreational equipment are presented in the next section.

At this time, EPA does not have deterioration data on large spark-ignition engines. However, EPA currently believes that larger uncontrolled carbureted gasoline nonroad engines would likely deteriorate more similarly to on-highway light-duty gasoline truck engines from the 1960's and 1970's. [10] These older on-highway engine models used similar technology as today's large nonroad gasoline engines.

MOBILE5 includes emission factors and deterioration and tampering rates for on-highway heavy-duty gasoline engines. From this information, we can calculate the 'A' value in Equation 2 by dividing the deteriorated emission factor at 100,000 miles by the new engine emission factor (and subtracting 1). To capture carbureted engines, we looked at the 20-year average for the 1960 through 1979 model years. Also, MOBILE5 uses linear deterioration for heavy-duty gasoline engines which translates to a 'b' value of 1.0 in Equation 2.

As a check on these deterioration rates, we reviewed emission data from ten 1969 light-duty gasoline trucks in an EPA report titled "Procurement and Emissions Testing of 1969 and 1972/1973 Model Year Gasoline Powered Light Duty Trucks" (EPA-460/3-80-11). These trucks were emission tested in 1980 before and after engine maintenance. The ratio of the emissions before and after maintenance gives some insight into the emission deterioration of the engines. These data showed equivalent A values of 0.11 to 0.58 for HC, 0.31 to 0.39 for CO, and 0.05 to 0.10 for NOx. These data are consistent with the deterioration rates used in the final NONROAD2008a model (see Appendix 1). The ranges of 'A' values from the test data are due to reporting the averages with and without one truck that appeared to be an outlier.

At this time, we do not have any information on the deterioration of fuel-injected gasoline engines (without catalysts). MOBILE does not include emission rates for non-catalyzed engines with fuel injection because catalysts were introduced before fuel-injection into the on-highway market. Anecdotal information suggests that deterioration is low from these engines compared to deterioration in a catalyst. For instance, accepted emission deterioration test methods for current on-highway engines are performed by aging the catalyst to full life but using a relatively new engine. Because we do not have better information, EPA used the same deterioration coefficients for fuel-injected engines (without catalysts) as for carbureted engines.

To estimate the Phase 1 deterioration factors, we relied upon deterioration information for current Class IIb heavy-duty gasoline engines developed for the MOBILE6 emission model. Class IIb engines are the smallest heavy-duty engines and are comparable in size to many Large

SI engines. They also employ catalyst/fuel system technology similar to the technologies we expect to be used on Large SI engines. [11]

To estimate the Phase 2 deterioration factors, we relied upon the same information noted above for Phase 1 engines. The technologies used to comply with the proposed Phase 2 standards are expected to be further refinements of the technologies we expect to be used on Phase 1 Large SI engines. For that reason, we are applying the Phase 1 deterioration factors to the Phase 2 engines. [11]

Table 6 shows the deterioration factors used for large spark-ignition equipment.

Table 6
Deterioration Factors for Spark-Ignition Engines > 25 HP

| **Engine Tech Type** | **A** | | | | **b** | **Cap** |
|---|---|---|---|---|---|---|
| | **HC** | **CO** | **$NO_x$** | **PM** | | |
| Uncontrolled | | | | | | |
| G2GT25 (gas, 2-stroke, baseline) | 0.201 | 0.199 | 0 | 0.201 | 1 | 1 |
| G4GT25 (gas, 4-stroke, baseline) | 0.26 | 0.35 | 0.03 | 0.26 | 1 | 1 |
| LGT25 (LPG, baseline) | 0.26 | 0.35 | 0.03 | 0.26 | 1 | 1 |
| NGT25 (CNG, baseline) | 0.26 | 0.35 | 0.03 | 0.26 | 1 | 1 |
| Phase 1 | | | | | | |
| G4GT251 (gas, 4-stroke) | 0.64 | 0.36 | 0.15 | 0.26 | 1 | 1 |
| LGT251 (LPG) | 0.64 | 0.36 | 0.15 | 0.26 | 1 | 1 |
| NGT251 (CNG) | 0.64 | 0.36 | 0.15 | 0.26 | 1 | 1 |
| Phase 2 | | | | | | |
| G4GT252 (gas, 4-stroke) | 0.64 | 0.36 | 0.15 | 0.26 | 1 | 1 |
| LGT252 (LPG) | 0.64 | 0.36 | 0.15 | 0.26 | 1 | 1 |
| NGT252 (CNG) | 0.64 | 0.36 | 0.15 | 0.26 | 1 | 1 |

## Deterioration Inputs for Recreational Equipment

The deterioration factors currently used in NONROAD for recreational equipment (i.e., snowmobiles, all-terrain vehicles, and offroad motorcycles) are based on those used in the final rulemaking for recreational equipment and large spark-ignition engines. [9]

The two-stroke versions of the recreational equipment engines are assigned deterioration values equal to the G2N2 tech type shown in Table 2, but they use different tech type names since the emission factors differ from the other engine applications. Four-stroke versions of these recreational equipment engines use deterioration rates based on pre-1978 uncontrolled four-stroke on-highway motorcycles from the MOBILE model. [12]

Table 7 shows the deterioration factors used for recreational equipment.

Table 7
Deterioration Factors for Offroad Motorcycles, All-Terrain Vehicles, and Snowmobiles

| **Equipment/Tech Type** | **A** | | | | **b** | **Cap** |
|---|---|---|---|---|---|---|
| | **HC** | **CO** | **NOx** | **PM** | | |
| Precontrol 2-stroke offroad motorcycles (RM2) | 0.201 | 0.199 | 0 | 0.2 | 1 | 1 |
| Precontrol 4-stroke offroad motorcycles (RM4) | 0.15 | 0.17 | 0 | 0.15 | 0.5 | 1 |
| Closed crankcase 4-stroke offroad motorcycles (RM40) | 0.15 | 0.17 | 0 | 0.15 | 0.5 | 1 |
| Phase 1 4-stroke offroad motorcycles (RM41) | 0.15 | 0.17 | 0 | 0.15 | 0.5 | 1 |
| Precontrol 2-stroke all terrain vehicles (RA2) | 0.201 | 0.199 | 0 | 0.2 | 1 | 1 |
| Precontrol 4-stroke all terrain vehicles (RA4) | 0.15 | 0.17 | 0 | 0.2 | 0.5 | 1 |
| Closed crankcase 4-stroke all terrain vehicles (RA40) | 0.15 | 0.17 | 0 | 0.15 | 0.5 | 1 |
| Phase 1 4-stroke all terrain vehicles (RA41) | 0.15 | 0.17 | 0 | 0.15 | 0.5 | 1 |
| Precontrol 2-stroke snowmobiles (RS2) | 0.201 | 0.199 | 0 | 0.2 | 1 | 1 |
| Modified 2-stroke snowmobiles (RS21) | 0.201 | 0.199 | 0 | 0.2 | 1 | 1 |
| Direct Injection 2-stroke snowmobiles (RS22) | 0.201 | 0.199 | 0 | 0.2 | 1 | 1 |
| Closed crankcase 4-stroke snowmobiles (RS40) | 0.15 | 0.17 | 0 | 0.15 | 0.5 | 1 |

## Deterioration Inputs for Recreational Marine Spark-Ignition Engines

Deterioration factors for sterndrive/inboard engines are those used in the draft NONROAD2004 model. They are based on information gathered for the recreational marine engine rulemaking. [13] Deterioration factors for outboard and personal watercraft have been updated starting with the NONROAD2005 model, using 1998-2005 model year emissions certification data for these engines. [14]

The technology class descriptions and associated designations, which are used in the NONROAD model, are shown in Table 8. The deterioration values for each technology class by designation are shown in Table 9.

Table 8
Marine Engine Technology Class and Designations

| Technology Class Differentiation | | | | Class Designation | | |
|---|---|---|---|---|---|---|
| Type | Cycle | Fuel System | Aftertreatment | NONROAD 2004 | NONROAD 2005 | NONROAD 2008a |
| Outboard | 2-Stroke | Carbureted | none | M1 | MO2C | MO2C |
| | | Carburetor Modifications | none | M5 | -- | -- |
| | | Carbureted | 3- Way Catalyst | M6 | -- | -- |
| | | Indirect Injection | none | M8 | MO2I | MO2I |
| | | Direct Injection | none | M9 | MO2D | MO2D |
| | 4-Stroke | Carbureted | none | M4 | MO4C | MO4C |
| | | Indirect Injection | none | -- | MO4I | MO4I |
| | | Direct Injection | none | -- | MO4D | MO4D |
| | Meets 2010+ standards | | | -- | -- | MOC1 |
| PWC | 2-Stroke | Carbureted | none | M2 | MP2C | MP2C |
| | | Carburetor Modifications | none | M14 | -- | -- |
| | | Carbureted | 2- Way Catalyst | -- | MP2CA | MP2CA |
| | | Indirect Injection | none | -- | MP2I | MP2I |
| | | Direct Injection | none | -- | MP2D | MP2D |
| | 4-Stroke | Carbureted | none | M13 | MP4C | MP4C |
| | | Indirect Injection | none | -- | MP4I | MP4I |
| | | Direct Injection | none | -- | MP4D | MP4D |
| | Meets 2010+ standards | | | -- | -- | MPC1 |
| SD/I ≤600 hp | 4-stroke | Carbureted | none | M3 | MS4C | MS4C |
| | | Direct Injection | none | M10 | MS4D | MS4D |
| | Meets 2010+ standards | | | -- | -- | MSC1 |
| SD/I >600 hp | 4-stroke | Carbureted | none | M3 | MS4C | MS4C |
| | | Direct Injection | none | M10 | MS4D | MS4D |
| | Meets 2010+ standards | | | -- | -- | MS4X |

Table 9
Deterioration Factors for Recreational SI Marine Engines

| Technology Class | A | | | | b | Cap |
|---|---|---|---|---|---|---|
| | HC | CO | NOx | PM | | |
| MO2C, MP2C | 0.00 | 0.00 | 0.00 | 0.00 | 1 | 1 |
| MO2I, MP2I | 0.03 | 0.03 | 0.08 | 0.00 | 1 | 1 |
| MO2D, MP2D | 0.03 | 0.03 | 0.05 | 0.00 | 1 | 1 |
| MP2CA | 0.26 | 0.26 | 0.06 | 0.00 | 1 | 1 |
| MO4C, MP4C | 0.05 | 0.05 | 0.05 | 0.00 | 1 | 1 |
| MO4I, MP4I | 0.03 | 0.03 | 0.03 | 0.00 | 1 | 1 |
| MO4D, MP4D | 0.03 | 0.03 | 0.03 | 0.00 | 1 | 1 |
| MS4C, MS4D | 0.26 | 0.35 | 0.03 | 0.26 | 1 | 1 |
| MOC1, MPC1 | 0.05 | 0.05 | 0.05 | 0.00 | 1 | 1 |
| MSC1 | 0.64 | 0.36 | 0.15 | 0.26 | 1 | 1 |
| MS4X | 0.26 | 0.35 | 0.03 | 0.26 | 1 | 1 |

## Liquid Petroleum and Compressed Natural Gas Spark-Ignition Engines

Because liquid petroleum gas (LPG) and compressed natural gas (CNG) engines are primarily four-stroke engines, the EPA decided to assume that they would deteriorate at the same rate as the corresponding gasoline-powered four-stroke SI engines for all pollutants. The EPA is not aware of any deterioration data available for LPG and CNG engines and requests that commenters submit any such data they may have to EPA. If such data become available, EPA will revise the deterioration rates for these engines in NONROAD accordingly.

## Example Calculation

The following example illustrates how deterioration factors (DFs) are calculated in NONROAD.

Example: Calculate the $NO_X$ deterioration factor for a ten year old 300-600 hp 4-stroke inboard/sterndrive recreational marine engine in 2020. (In NONROAD, ten year old equipment in 2020 translates to equipment made in model year 2011, since the calendar year of interest is assigned age =1 year).

The deterioration factor, DF, is calculated as:

$$DF = 1 + A*\frac{\text{(cumulative hours * load factor)}}{\text{median life at full load, in hours}} \quad \text{[Equation 4]}$$

where: MSC1 $NO_X$ Deterioration "A" = 0.15 (from Table 9)
Activity = 47.6 hours/year (from activity.dat input file)

Load factor = 0.21 (from activity.dat input file)
Median life = 197 hours (from pop input file)
Cumulative hours = age * activity = 10*47.6 = 470.6 hours

Substituting the above values into the equation yields:

$$DF = 1 + 0.15 * \frac{(470.6 * 0.21)}{197} = 1 + 0.15 * 0.507 = 1.076$$

**References**


1. "Control of Emissions From Nonroad Spark-Ignition Engines and Equipment; Final Rule," 73 FR 59034, October 8, 2008.

2. "Emissions for New Nonroad Spark-Ignition Engines At or Below 19 Kilowatts; Final Rule," 60 FR 34581, July 3, 1995.

3. "Phase 2: Emission Standards for New Nonroad Nonhandheld Spark Ignition Engines At or Below 19 Kilowatts," 64 FR 15207, March 30, 1999.

4. "Phase 2: Emission Standards for New Nonroad Spark-Ignition Handheld Engines At or Below 19 Kilowatts and Minor Amendments to Emission Requirements Applicable to Small Spark-Ignition Engines and Marine Spark-Ignition Engines; Final Rule," 65 FR 24268, April 25, 2000.

5. "Final Rule for New Gasoline Spark-Ignition Marine Engines; Exemptions for New Nonroad Compression-Ignition Engines at or Above 37 Kilowatts and New Nonroad Spark-Ignition Engines at or Below 19 Kilowatts," 61 FR 52088, October 4, 1996.

6. "Control of Emissions From Nonroad Large Spark-Ignition Engines and Recreational Engines (Marine and Land-Based); Final Rule," 67 FR 68241, November 8, 2002.

7. "Updates to Phase 2 Technology Mix, Emission Factors, and Deterioration Rates for Spark-Ignition Nonroad Nonhandheld Engines at or below 19 Kilowatts for the NONROAD Emissions Inventory Model," EPA Memorandum from Phil Carlson to Docket EPA-HQ-OAR-2004-0008, March 6, 2007.

8. "Phase 3 Technology Mix, Emission Factors, and Deterioration Rates for Spark-Ignition Nonroad Nonhandheld Engines at or below 19 Kilowatts for the NONROAD Emissions Inventory Model for the Final Rule," EPA Memorandum from Phil Carlson to Docket EPA-HQ-OAR-2004-0008, May 21, 2008.

9. Final Regulatory Support Document: Control of Emissions from Unregulated Nonroad Engines, Chapter 6, Office of Air and Radiation, EPA420-R-02-022, September 2002.

10. "Revisions to the June 2000 Release of NONROAD to Reflect New Information and Analysis on Marine and Industrial Engines," EPA memorandum from Mike Samulski to Docket A-98-01, November 2, 2000, Docket A-2000-01, Document II-B-08.

11. Proposed Control of Emissions from Nonroad Large Spark Ignition Engines, Recreational Engines (Marine and Land-based), and Highway Motorcycles, Regulatory Support Document, EPA420-D-01-004, September 2001, Chapter 6.

12. "Emission Modeling for Recreational Equipment," EPA Memorandum From Linc Wehrly to Docket A-98-01, November 13, 2000.

13. "Deterioration Factors for Existing Technology, Gasoline, Outboard Marine Engines," EPA memorandum from Mike Samulski to Chester J. France, Director, Engine Programs and Compliance Division, March 4, 1996.

14. "Updates to Technology Mix, Emissions Factors, Deterioration Rates, Power Distribution, and Fuel Consumption Estimates for SI Marine Engines in the NONROAD Emissions Inventory Model," EPA Memorandum From Mike Samulski to Docket EPA-HQ-OAR-2004-0008, November 30, 2005.

Appendix 1

**Deterioration Ratio Data for 1969 MY LDGTs**