A Technical Assessment of E10 and E20 Petrol Ethanol Blends Applied to Non-Automotive Engines.

Failure Mode and Effects Analysis of Engine Function and Component Design for Mercury Marine 15hp Outboard and Stihl FS45 Line-Trimmer Engines.

Report to Environment Australia

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Orbital Engine Company

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1 Overview

The purpose of this report is to identify potential sources of system function failure of typical non-automotive engine applications, when used with ethanol-blended E20 fuel. The report also identifies possible sources of component failure, through the use of ethanol-blended E20 fuel, on two engine applications. The selected applications for investigation were a 15hp Outboard marine engine and a Line-trimmer engine.

A technique termed Failure Mode and Effect Analysis (FMEA) was used to perform the functional and design FMEAs detailed in this report. This technique is used throughout industry to enable objective assessment of designs, processes, systems and functions.

A functional FMEA was used to investigate the effect of ethanol-blended E20 fuel on various engine functions (eg cold start, idle). The FMEA technique was repeated on four engine groups defined by typical applications. The groups were: Aircraft; Utility; Marine and Vehicle engines. The FMEA identified that investigation is required to determine the effects of E20 fuel on numerous engine functions.

The results of the functional FMEA tend to be biased as the data reflects test programs that are in place to evaluate engine operation on E10 and E20 fuels. This is illustrated in Figure 5, where aircraft and vehicle engine groups exhibit the highest risk priority number (RPN) since these engine groups show the highest detection rating (no control in place to detect failure). It must be noted that the RPN for the aircraft group is higher than the vehicle group due to the severity rating shown in Figure 1.

Of particular concern is the use of E10 and E20 fuel for aircraft applications. Due to associated risks of engine failure, the use of E10 and E20 fuel use for this application is not recommended without successful completion of a comprehensive testing program approved by the appropriate aviation authorities.

A design FMEA was used to investigate the effect of ethanol-blended E10 and E20 fuel on the components of a 15hp Outboard marine engine and a Line-trimmer engine. The design FMEA for both engines highlighted the possibility of engine failure through: material compatibility with E10 and E20 fuel; enleanment; and gumming. Material compatibility was found to potentially cause engine damage through corrosion of critical bearing surfaces and external fuel leaks. Enleanment occurs as a result of the E10 and E20 fuel properties and leads to knock and pre-ignition in engines intended for use with regular gasoline. This effect was found to be potentially the main source of base engine component failure. Gumming was highlighted as a potential failure mode, due to the potential risk of fuel residues depositing on critical surfaces or causing blockages within components.

The FMEAs performed have investigated the effect of the use of E10 and E20 fuel on engine function. The analyses have highlighted potential failure modes and mechanisms of failure.

The FMEA technique is a valuable tool to identify potential component/ system design or functional issues, however rigorous verification techniques are required to fully ascertain functionality compliance. The outcome of an FMEA is a list of functions and components with an assigned objective risk priority number (RPN). The RPN is typically used to identify and rank the priority of components and functions that require verification. In conjunction with other inputs such as: warranty data; design studies; competitive analysis; etc, the FMEA is used to generate a verification plan that details the necessary analysis and testing required for validating component and/ or system function.

The potential failure modes as identified by the FMEAs presented in this report, require appropriate testing to establish whether these are in fact issues affecting the function of non-automotive engine applications, when used with ethanol-blended E10 and E20 fuel.

2 A description of the FMEA

2.1 What is a FMEA?

A FMEA is a systematic approach that utilises a tabular method to aid the thought processes used by engineers to identify potential failure modes and their effects. Its purpose is to identify potential failure modes, rate the severity of their effects and rank in order the likelihood of their occurrence.

The contents of a FMEA may be based on a number of inputs or information sources, for example;

- Design requirements
- Other studies
- Engineers previous knowledge
- Supporting documentation and reports
- Where possible information gathered from in-field performance for example warranty return information.

As such the FMEA procedure outputs a document that indicates what may occur, the associated causes and the means of addressing those occurrences.

2.1.1 The FMEA team selection.

The engineer responsible for the FMEA has chosen team members ensuring as wide a ranging skill and experience base. The team then went about selecting the format for the FMEA as well as identifying the approach for the FMEA.

2.1.2 The FMEA format.

The format selected by the FMEA team members was that of the design FMEA as this format is suitable to carry out a FMEA for components and it is the logical structure of the FMEA process that is to be utilised. The team adopted the functional approach as most suitable.
The FMEA studies completed, follow the format described by the Ford Worldwide FMEA document [21], it utilises a similar layout of the form shown in [21]. The complete process of the design FMEA has not been followed here, as only the potential failure modes and their effects inclusive of safety concerns are to be documented. In fact the design FMEA should be completed before the product is released to the market. The other outputs from the design FMEA, planning product design verification test programs and establishing a priority for design improvement actions, etc. are not pursued as it is outside the scope of this study and are vehicle manufacturer related issues.

2.2 FMEA columns descriptions

These following descriptions are provided to allow readers who are unfamiliar with FMEA's to understand the FMEA study without having to refer to the Ford handbook [21]. The reader may like to view one of the FMEA studies in the appendix section of this report while reading the following FMEA column descriptions.

2.2.1 Item and Function

This column lists every component that may be affected either directly or indirectly by the E20 ethanol blend fuel. There is also a description of the function of the item as the team adopted the functional approach to the FMEA.

2.2.2 Potential failure mode

This column lists all the potential failure modes for each item. A failure mode is considered to have occurred when the component ceases to operate in the correct manner. For example, the fuel tank should neither corrode nor perish, if either occurs then these are modes of failure induced by the potential cause or mechanism of the failure. The hardware or component based approach has been adopted as each part has been listed.

2.2.3 Potential effect of failure

This column lists all the possible effects of a failure mode. These effects are the consequences of a failure mode in terms of their impact on other systems, the vehicle and the customer or government regulations. For example when the fuel tank perishes or corrodes the effect of this failure is a fuel leak.

2.2.4 Severity

This column contains a rating on a 1 to 10 scale of the seriousness of the effect(s) of a potential failure mode. The rating table of severity is shown below.

Table 1 Severity rating table

Effect	Rating	Criteria
No effect	1	No effect
Very slight effect	2	Customer not annoyed. Very slight effect on vehicle or system performance
Slight effect	3	Customer slightly annoyed. Slight effect on vehicle or system performance
Minor effect	4	Customer experiences minor annoyance. Minor effect on vehicle or system performance
Moderate effect	5	Customer experiences some dissatisfaction. Moderate effect on vehicle or system performance
Significant effect	6	Customer experiences discomfort. Vehicle performance degraded but operable and safe. Partial loss of system function but operable.
Major effect	7	Customer dissatisfied. Vehicle performance severely affected but driveable and safe system function impaired
Extreme effect	8	Customer very dissatisfied. Vehicle inoperable but safe. System inoperable
Serious effect	9	Potential hazardous effect. Able to stop vehicle without mishap, gradual failure. Compliance with government regulations in jeopardy
Hazardous effect	10	Hazardous effect. Safety related sudden failure non compliance with government regulations

2.2.5 Potential cause/mechanism of failure

This column lists the design deficiencies of a component that result in the failure mode. For example if the fuel tank perishes or corrodes then the design deficiency is that the tank was constructed from either the incorrect material or an incorrect surface treatment for use with the E20 ethanol blend was utilized.

2.2.6 Occurrence

This column lists the estimated cumulative number of component failures (CNF) that could occur for a given cause over the design life of the component. The rating table of occurrence is shown below.

Table 2 Occurrence rating table

Occurrence	Rating	CNF/1000	Criteria
Almost impossible	1	<0.00058 (1 in 1,500,000)	Failure unlikely
Remote	2	0.0068 (1 in 150,000)	Rare number of failures likely
Very slight	3	0.063 (1 in 15,000)	Very few failures likely
Slight	4	0.46 (1 in 2000)	Few failures likely
Low	5	2.7 (1 in 400)	Occasional number of failures likely
Medium	6	12.4 (1 in 80)	Medium number of failures likely
Moderately high	7	46 (1 in 20)	Moderately high number of failures likely
High	8	134 (1 in 8)	High number of failures likely
Very high	9	316 (1 in 3)	Very high number of failures likely
Almost certain	10	>316 (1 in 3)	Failure almost certain to occur

In order to apply scaling to the occurrence ratings the FMEA team decided on the following ratings.

A rating of 10 will be applied to the following:

- All components specifically mentioned as having the potential for failure or exhibiting problems by the reference material.
- All components or subcomponents specifically mentioned as requiring replacement or redesign for use with the E20 ethanol petrol blend by stakeholders.

For all other items, an estimated rating agreed on by the FMEA team is applied.

2.2.7 Current Design Controls

A design control is a method or test used to either detect a cause of a potential failure mode or to detect a failure mode. Within the E20 program, engine durability, emissions and components compatibility testing is targeted as the design control methods available for detection.

2.2.8 Detection

The detection rating is scaled from 1 to 10 where 1 indicates an almost certain likelihood that a design control method or test will detect a first level cause of a potential failure mode and a 10 indicates that detection is almost impossible, either because no design control method is available or none is planned. Table 3 shown below presents the ratings and how they relate to the design control chosen.

Table 3 Detection rating table

Effect	Rating	Criteria: Design Control
Almost Certain	1	Has the highest effectiveness in each applicable category
Very high	2	Has very high effectiveness
High	3	Has high effectiveness
Moderately high	4	Has moderately high effectiveness
Medium	5	Has medium effectiveness
Low	6	Has low effectiveness
Slight	7	Has very low effectiveness
Very Slight	8	Has lowest effectiveness in each applicable category
Remote	9	Is unproven, unreliable or effectiveness unknown
Almost impossible	10	No Design Control method available or none planned

2.2.9 Risk Priority Number

Risk Priority Number (RPN) is the product of the occurrence, severity and detection ratings. The RPN should only be used to rank the concerns, as the ratings and final RPN numbers have no value or meaning in themselves.

3 Functional FMEA

A functional FMEA was performed to determine the effect of E20 fuel on engine functions for selected engine groups. Appendix A to Appendix D contains the completed function FMEA tables.

3.1 Engine Groups

In an attempt to rationalise the extensive range of non-automotive engine applications four engine groups were created. The groups were, aircraft, utility, marine and vehicle. Table 4 below illustrates examples of engines in each group.

Table 4 Example of an engine application within nominated engine groups

Engine Group	Example
Aircraft	Ultra-light, hovercraft, light air craft
Utility	Line-trimmer, chainsaw, lawn mower, generator, compressors
Marine	Outboards, personal water craft
Vehicle	Snowmobile, motorcycle, all terrain vehicles

3.2 Engine Functions

Functions that a typical non-automotive engine must be able to perform are shown in Table 5. This information formed the basis for the functional FMEA on the four engine groups.

Table 5 Engine functions and definitions

Item	Function Description
Cold Start	Commence engine operation
Hot Start	Recommence engine operation
Warm-up	Engine operation before reaching operating temperature
Idle	Operation at lowest power required to drive equipment
Part Load	Engine operating point between idle and full load
Full Load	Engine operating point full throttle
Speed Control	Engine operation for constant speed varying load
Load Control	Torque backup
Over-speed	Limit maximum engine speed
Over-run	When device drives engine
Shutdown	Cease engine operation

3.3 Potential Failure Modes

Potential failure modes for the engine functions were found to be the same for all engine groups. Table 6 illustrates potential failure modes for specified engine functions.

Table 6 Potential failure modes for engine functions

Item / Function	Potential Failure Mode
Cold Starting -To commence engine operation	Engine fails to start Start time is excessive Engine starts then stalls
Hot Starting -To recommence engine operation	Engine fails to start Start time is excessive Engine starts then stalls
Warm-up - Engine operation when Not at operating temperature	Engine stalls Engine power output low Engine Not efficient Rough engine operation
Idle -Operation at lowest engine power while driving equipment	Engine stalls Rough engine operation Inefficient operation
Part Load -Engine operating point between idle and full load	Engine stalls Engine seizure Rough engine operation Inefficient operation
Full Load -Engine operating point full throttle	Engine stalls Engine seizure Rough engine operation Inefficient operation Lack of power
Speed Control -Engine operation for constant speed varying load	Engine damage Inefficient operation Inaccurate control Poor control to Nominal speed Engine exceed maximum engine speed
Load Control - Torque backup	Engine Stalls Inaccurate control Engine cannot maintain load Engine damage
Over-speed -Function to limit maximum engine speed	Engine failure Poor speed control Engine over-speed
Shutdown -Cease engine operation	Ignition kill does Not stop engine

3.4 Potential Effect of Failure

For all engine groups, potential effects of failure were found to be similar, though subtle differences did exist depending on the application. For example if an aircraft engine stalls at altitude then it will lose altitude, whereas a vehicle remains stationary. A consequence of the difference in effects of failure alters the severity rating for each engine group.

3.5 Severity Rating

Severity ratings were developed for the engine functions of each engine group. Figure 1 illustrates the severity rating for each engine function and engine group. The severity ratings are generally highest for aircraft applications since any failure may cause personal injury. Failure to adequately limit over-speed and perform shutdown were given a high rating for utility engine group due to the potential for operator injury.

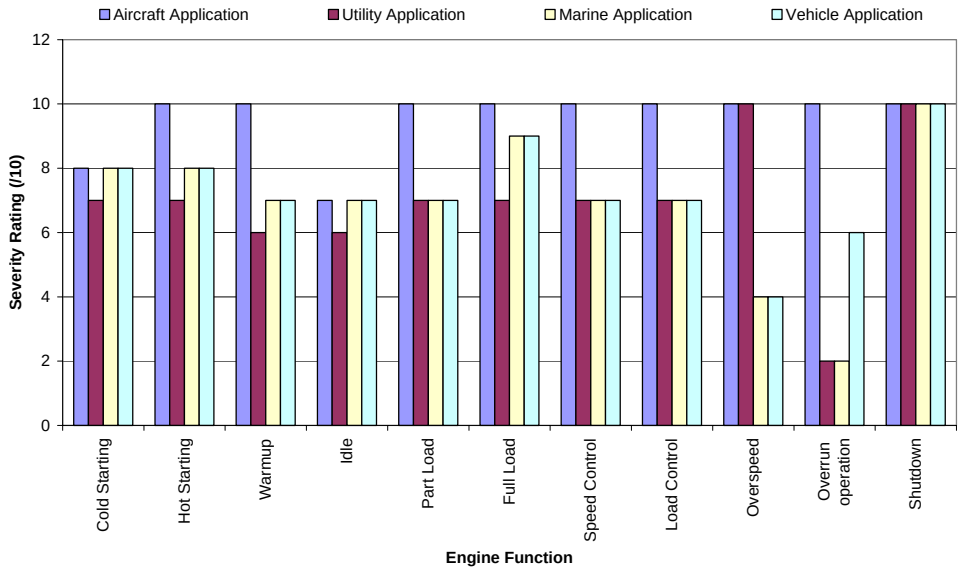

Figure 1 Severity rating for each function and engine group

3.6 Potential Cause(s)/ Mechanism(s) of Failure

Potential causes of failure are generally the same for all engine groups. The majority of the mechanisms for failure are related to fuel properties.

3.7 Occurrence Rating

No statistics were available to provide satisfactory reference for an occurrence rating. A document survey (list appears in References) was conducted to determine which mechanisms were likely to cause function failure. The results of this appear in Figure 2. Using this information it was possible to develop subjective occurrence ratings for the failure of a specific engine function. Figure 3 illustrates occurrence values assigned to engine functions.

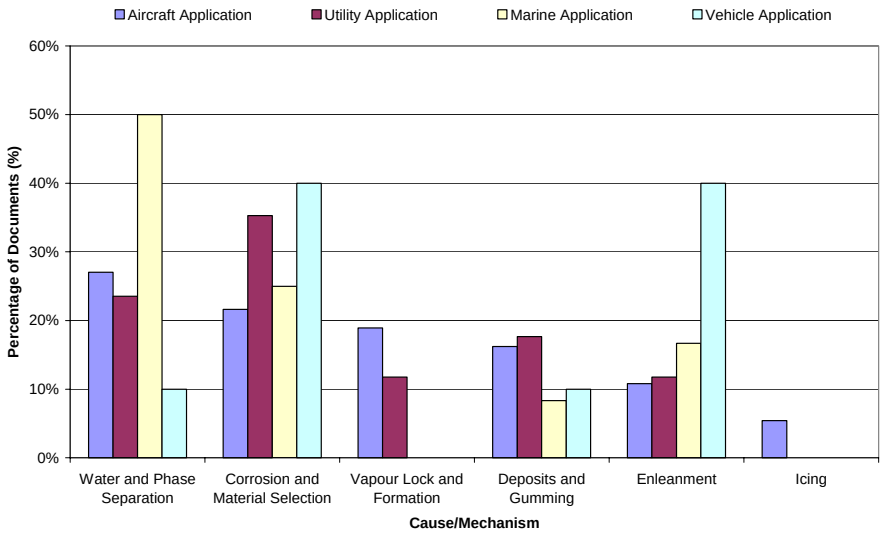

Figure 2 Results of document search on failure mechanisms

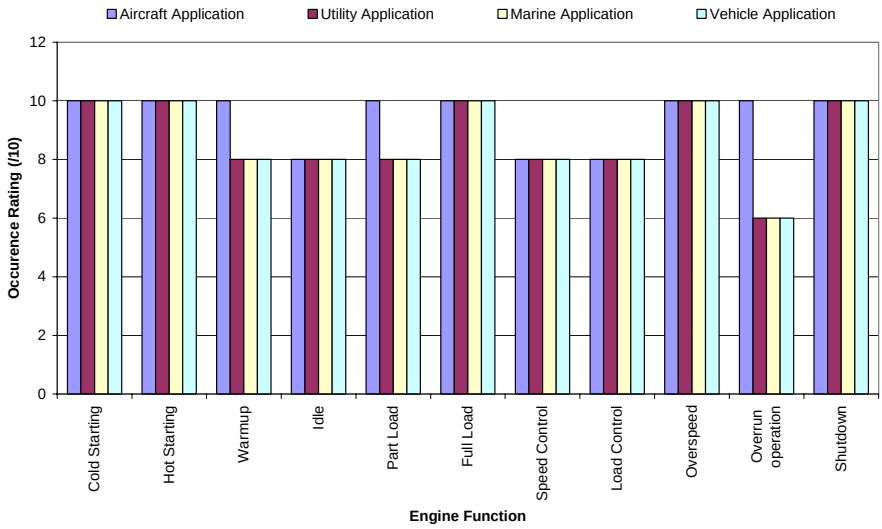

Figure 3 Occurrence rating for engine function and engine groups

3.8 Current Design Controls

Current design controls are dependant on testing performed as part of the E10 and E20 Ethanol test program. Limited testing is being performed on only one example from engine groups Marine and Utility. Table 7 lists the current design controls for engine function for each engine group. Note that many items are listed as “No controls in place” because testing is not being undertaken.

Table 7 Current design controls for engine function for each engine group

	Current Design Control			
Item / **Function**	Aircraft	Utility	Marine	Vehicle
Cold Starting -To commence engine operation	No controls in place	Engine Testing	Engine Testing	No controls in place
Hot Starting -To recommence engine operation	No controls in place	Engine Testing	Engine Testing	No controls in place
Warm-up -Ensure engine operation when Not at operating temperature	No controls in place	Engine Testing	Engine Testing	No controls in place
Idle -Operation at lowest engine power while driving equipment	No controls in place	Engine Testing	Engine Testing	No controls in place
Part Load -Engine operating point between idle and full load	No controls in place	Engine Testing	No controls in place	No controls in place
Full Load -Engine operating point full throttle	No controls in place	Engine Testing	Engine Testing	No controls in place
Speed Control -Engine operation for constant speed varying load	No controls in place	No controls in place	No controls in place	No controls in place
Load Control - Torque backup	No controls in place	No controls in place	No controls in place	No controls in place
Over-speed -Function to limit maximum engine speed	No controls in place	Engine Testing	No controls in place	No controls in place
Over-run operation -Engine operation when device drives engine	No controls in place	No controls in place	No controls in place	No controls in place
Shutdown -Cease engine operation	No controls in place	Engine Testing	Engine Testing	No controls in place

3.9 Detection Rating

Detection ratings assigned to failure of engine functions are shown in Figure 4. Note that the majority of the detection ratings have a value of 10 since no control is in place to establish failure of the specific function. This action results in a high detection rating, hence biasing the RPN. Several functions within the marine and utility engine groups were assigned detection values of 1 since it is expected that testing to be performed as part of the E20 test program will detect failures of these functions.

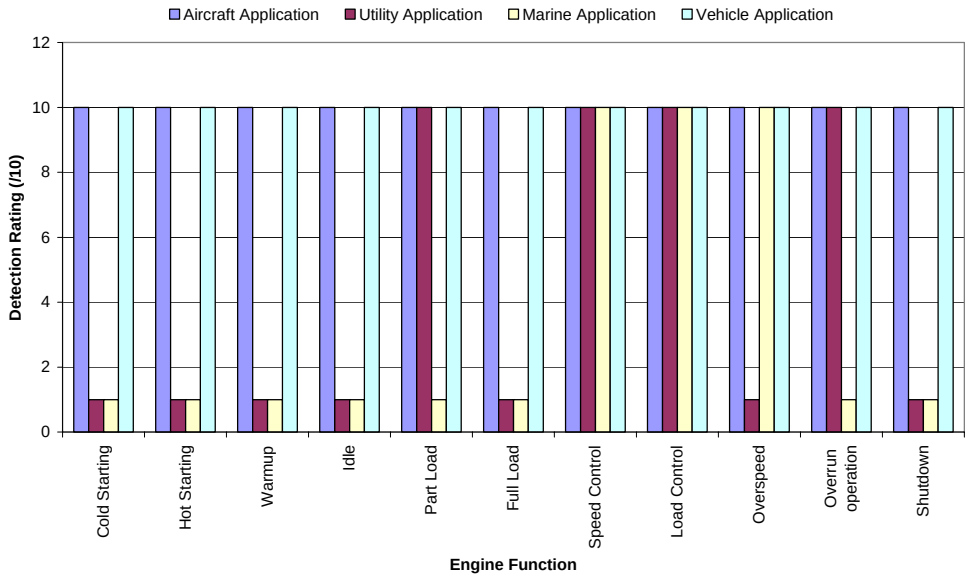

Figure 4 Detection Rating for engine functions and engine groups

3.10 Risk Priority Number

Risk priority number for each engine function is shown in Figure 5. The aircraft and vehicle groups have the highest RPN values. The lower RPN values of the utility and marine engine groups are a reflection of the test program being performed on these engine groups.

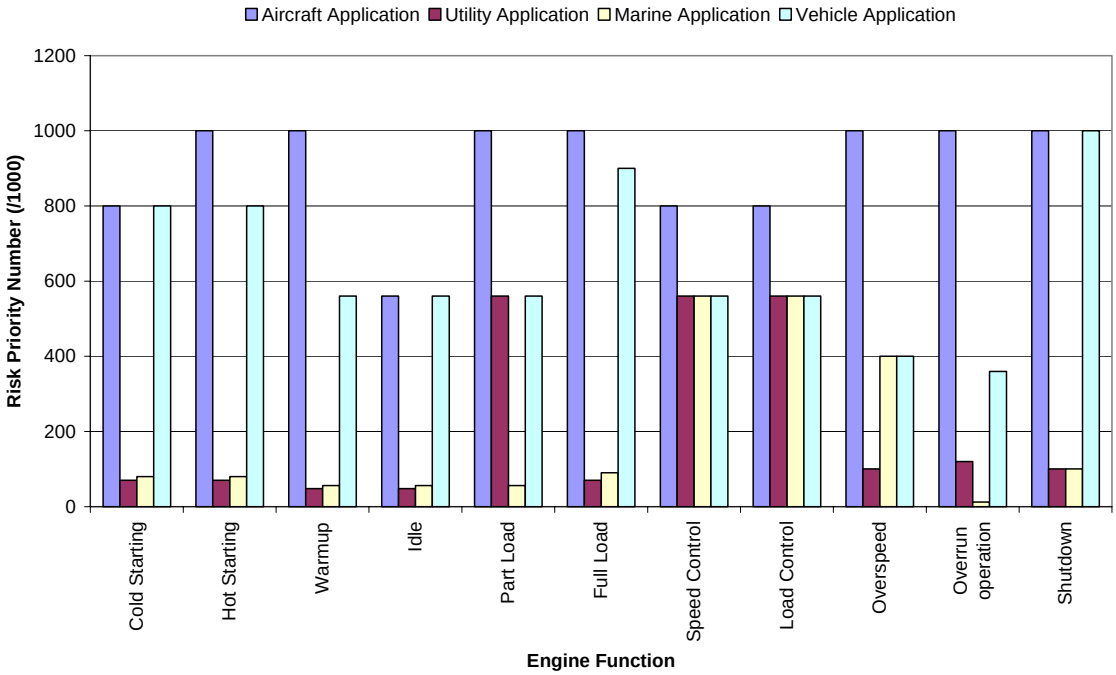

Figure 5 Risk priority number for engine function and engine groups

3.11 Summary of Function FMEA

A functional Failure Mode FMEA was used to investigate the effect of ethanol-blended fuel E20 on various engine functions (eg cold start, idle). The FMEA technique was repeated on four engine groups defined by typical applications. The groups were: Aircraft, Utility, Marine and Vehicle engines.

The results of the functional FMEA tend to be biased as the RPN reflects test programs that are in place to evaluate engine operation on E10 and E20 fuels. This is illustrated in Figure 5, where aircraft and vehicle engine groups exhibit the highest risk priority number (RPN) since these engine groups show the highest detection rating (no control in place to detect failure). It must be noted that the RPN for the aircraft group is higher than the vehicle group due to the severity rating shown in Figure 1.

Of particular concern is the use of E20 fuel for aircraft applications. Due to associated risks of engine failure, it is recommended that E20 use for this application be deferred until comprehensive testing is completed and E20 use approved by suitable aviation authorities.

The FMEA has identified that further investigation is required to determine the effects of E10 and E20 fuel on a number of engine functions not addressed by the test program being undertaken on the outboard and line-trimmer engines. Speed control function is a particularly important function for the utility group when an engine may be used to drive machinery at a constant speed with varying load (for example a generator set, concrete mixer, mulcher). Load control (torque back up) is an important function for all engine groups since this function is a fundamental requirement for an engine driving rotating equipment. Over-speed control is an important function since engine durability in all groups is dependant on this function.

The current test program will provide good insight to most issues likely to occur as a result of using ethanol-blended fuels. However, as discussed above, there are specific functions that will not be addressed. Therefore any subsequent test programs should consider including verification of: speed control, load control for all engine groups; part load for utility group; and over-speed for marine and vehicle groups.

4 Design FMEA - 15hp Mercury Marine Outboard

A design FMEA was conducted on a 2002 model year 15hp two-stroke Mercury Marine outboard engine. This engine was considered to be representative of engines in the marine group. The FMEA exercise was limited to how component function may be impaired by using ethanol-blended fuels. The FMEA table is attached in Appendix E. A discussion of the FMEA analysis follows.

4.1 Item/ Function

The first step in conducting the FMEA was to list all engine components exposed to fuel and the associated functions that may be affected by the fuel. For example a fuel hose has two functions: transfer fuel and maintain connection with fuel connector. The listing of components and associated functions is shown in Appendix E. Figures of components and assemblies exposed to E20 fuel are illustrated in Appendix F.

4.2 Potential Failure Modes

The potential failure modes identified for the 15hp outboard engine are listed in detail in Appendix E. The failure modes relate to the failure of the component to perform the intended function.

4.3 Potential Effect(s) of Failure

Potential effects of failure are shown in Appendix E. The analysis found that many component function failures had the potential to create similar effects of failure. Potential effects of failure include:

- Lack of power
- Fuel leaks
- Engine stopping
- Rough engine operation
- Engine seizure
- Engine not starting
- Poor starting
- Throttle sticking

Figure 6 illustrates a summary of potential effects of failure and provides a percentage rating for each effect of failure. Lack of power and fuel leaks are the most common effect of potential function failure, followed by engine stopping and rough engine operation.

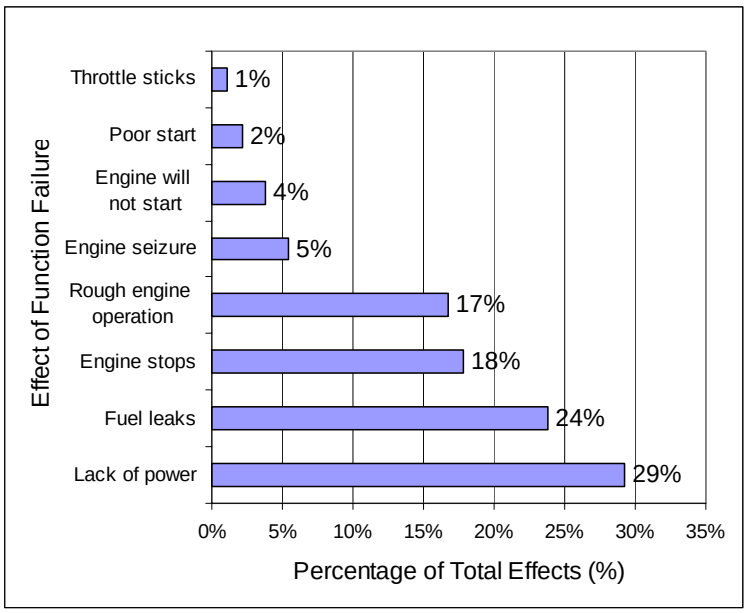

Figure 6 Effect of component function failure on engine

Figure 6 does not address the severity of the effect of function failure.

4.4 Severity Rating

Severity ratings were assigned based upon the effect of the failure mode. Figure 7 illustrates the severity ratings assigned for this FMEA

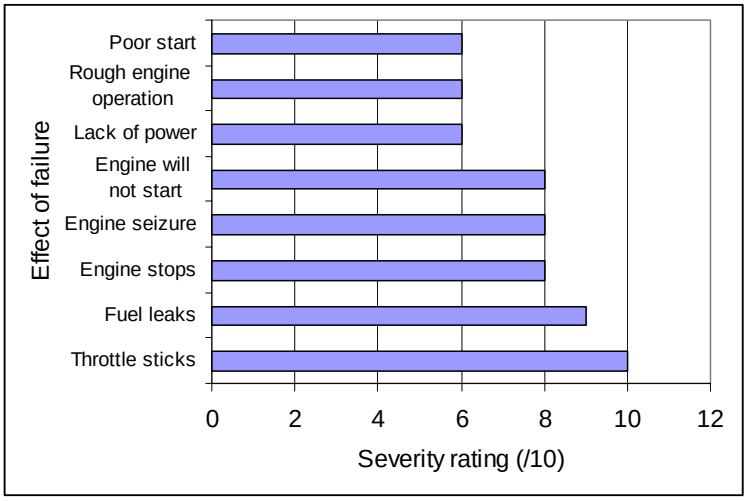

Figure 7 Severity rating of the effect of failure for components exposed to E20

Throttle sticking was assigned the maximum severity rating of 10 due to the possibility of the throttle being stuck wide-open during engine operation, with an associated operator safety risk.

Fuel leaks were assigned a value of 9, since their occurrence is potentially hazardous.

Failure effects that resulted in the engine being inoperable but safe were given a rating of 8.

Failure effects that resulted in degraded engine performance were assigned a severity rating of 6.

4.5 Potential Cause/ Mechanism of Failure

Potential causes of failure specific to E20 fuel, in order of significance, were found to be the following:

- Material degradation
- Gumming
- Lubrication deficiency
- Altered combustion
- Fuel properties

To summarise the potential mechanisms of failure, Figure 8 displays the proportion of mechanisms discussed in this analysis. This figure shows that material degradation (corrosion or perishing) is potentially the most significant function failure mechanism.

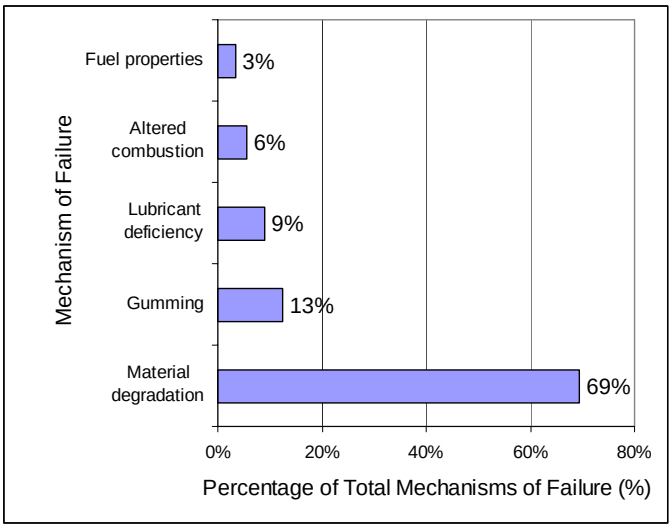

Figure 8 Mechanism of failure vs. Percentage of total

4.5.1 Material Degradation

Questionable material compatibility with E20 fuel is potentially the most common cause of function failure. This cause of failure potentially produces component degradation (corrosion and perishing), fuel leaks and incorrect fuel metering. Failure of fuel supply components (eg fuel tank, fuel tubing) has the potential to allow water into the fuel. Water contaminated fuel may be the result of several components not functioning correctly. Water contamination is a recognized failure mode for ethanol-blended fuel since it leads to phase separation. Water contamination in ethanol blend fuels also promotes aggressive corrosion of materials. Water contamination is also associated with lubrication failure resulting in high wear rates for components (including potential for engine seizure).

4.5.2 Gumming

Gumming is due to deposits, which may form on components from compounds within the fuel. Gumming may also be the result of the E20 fuel dissolving gasoline fuel residue and depositing it elsewhere. Gumming has the potential to block fuel metering or flow control devices (eg check valves and needle valves).

4.5.3 Lubrication Deficiency

Lubrication deficiency is a failure mechanism, which describes potential failures attributed to lubricating oil. The term captures several modes of lubrication failure, including; insufficient lubrication, unsuitable oil (for fuel used), lubrication failure, unsuitable or insufficient detergents in oil.

4.5.4 Altered Combustion

Combustion may be altered by a phenomenon known as enleanment. E20 fuel necessitates a richer air to fuel ratio for stoichiometric combustion than that necessary for regular gasoline. When using ethanol-blended fuels in engines designed for use of regular gasoline, the resulting air to fuel ratio is therefore leaner Enleanment has the potential to cause severe damage to base engine components through knock or pre-ignition. Enleanment may also occur through blockages in the fuel system components or metering orifice in the carburettor, due to material degradation or gumming.

4.5.5 Fuel Properties

Fuel properties will definitely have an effect on engine performance. For example it was found through the FMEA exercise that the ability of the carburettor to mix fuel and air might be inhibited by the fuels vaporisation properties. Another potential failure mechanism of fuel properties (or composition) is due to carbon deposits forming on the ports and piston ring grooves. Note that carbon deposit formation in ports or ring grooves is also a function of lubricating oil detergents and combustion temperatures.

4.6 Occurrence

No statistics were available to provide satisfactory reference for an occurrence rating. The FMEA team was consulted to determine likely occurrence ratings, based upon the potential cause of failure. Figure 9 illustrates occurrence ratings assigned by the FMEA team.

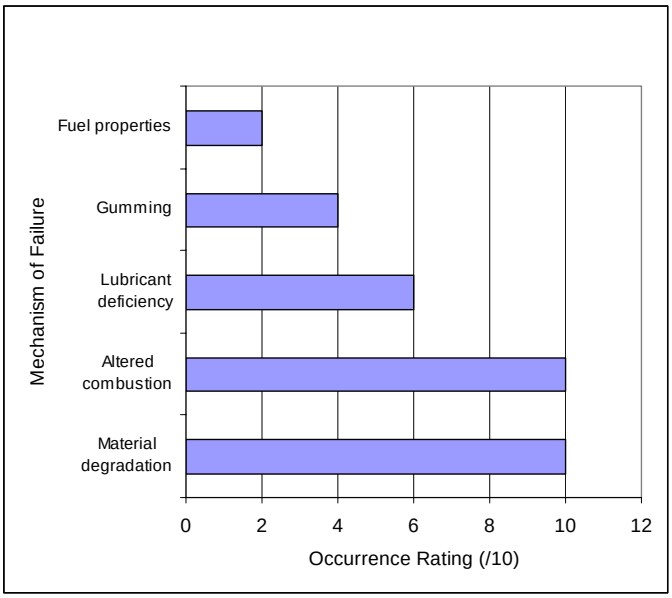

Figure 9 Occurrence rating for the cause of components exposed to ethanol-blended fuels

Occurrence ratings of 10 were assigned to causes of failure due to altered combustion. This cause is influenced by ethanol-blended fuels effect on combustion temperatures and hence the likelihood of damage to base engine components such as pistons, piston rings and sparkplugs. The FMEA team decided that it was impossible to determine an occurrence rating for these items, resulting in the assigned value of 10.

The occurrence values assigned to causes of failure due to material degradation was determined to be a 10. The FMEA team decided that it was impossible to determine an occurrence rating for these items, since little is known about the material specifications, resulting in the assigned value of 10.

4.7 Current Design Controls

Current design controls in place for the 15hp Mercury Marine engine include durability tank testing, emissions testing and materials compatibility testing.

4.8 Detection Rating

A detection rating of 1 (almost certain) was assigned to material compatibility tests. Engine testing was assigned a 3 since testing should detect component failures.

4.9 Risk Priority Number

Risk priority numbers ranged from 12 to 240. Risk priority numbers are illustrated in Figure 10.

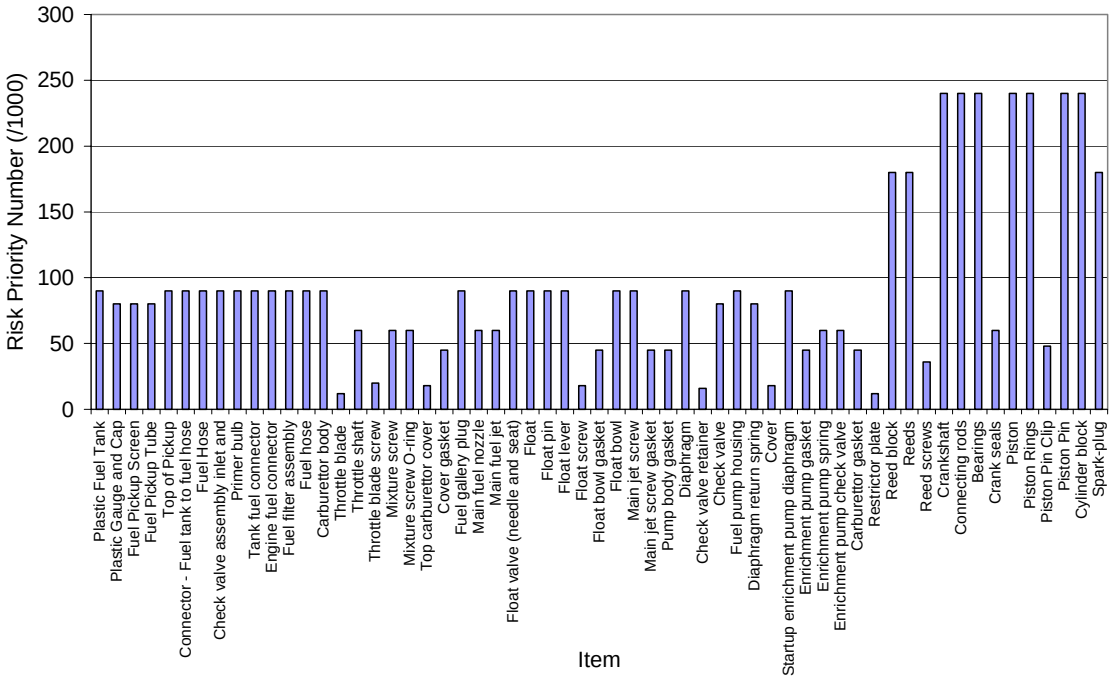

Figure 10 Risk priority number for components exposed to E20

The components analysed were grouped based on RPN ranking. Table 8 lists the components in RPN and group order. Components in Group A have the highest priority for validation of function.

Group A contains base engine components (eg crankshaft, pistons and bearings). An observation that can be made is the occurrence rating for these components is 10. There is a high expectation that the failure will be detected during engine testing (detection – 3). The potential failures are a result of the relatively unknown effect of ethanol-blended fuels effect on combustion and corrosion of critical bearing surfaces in an outboard marine engine.

Group B contains ancillary components that are critical to engine function. The components potential failure typically produces rough engine running, lack of power or poor engine starting (severity – 6). There is a high expectation that the failure will be detected during engine testing (detection – 3). The failure mechanisms are due to the relatively unknown effect of ethanol-blended fuels effect on combustion and material degradation

Group C components are manufactured from a variety of materials. The potential failure of the components is typically through material degradation. The failure would typically produce a fuel leak or stop the engine running (severity – 9). Material compatibility test should detect failure of these components (detection – 1)

Group D is the lowest risk category. Failure of group D components can have a variety of effects, from engine stopping to fuel leaks, however the likely occurrence of these failures ranks them low on the RPN scale.

Table 8 Outboard components severity rating, occurrence rating, detection rating and risk priority number

Item	Severity rating	Occurrence rating	Detection rating	Risk priority number
GROUP A	**RPN>180**			
Crankshaft	8	10	3	240
Connecting rods	8	10	3	240
Bearings	8	10	3	240
Piston	8	10	3	240
Piston Rings	8	10	3	240
Piston Pin	8	10	3	240
Cylinder block	8	10	3	240
GROUP B	**RPN=<180**			
Reed block	6	10	3	180
Reeds	6	10	3	180
Spark-plug	6	10	3	180
GROUP C	**RPN=<120**			
Plastic Fuel Tank	9	10	1	90
Top of Pickup	9	10	1	90
Connector - Fuel tank to fuel hose	9	10	1	90
Fuel Hose	9	10	1	90
Check valve assembly inlet and outlet	9	10	1	90
Primer bulb	9	10	1	90
Tank fuel connector	9	10	1	90
Engine fuel connector	9	10	1	90
Fuel filter assembly	9	10	1	90
Fuel hose	9	10	1	90
Carburettor body	9	10	1	90
Fuel gallery plug	9	10	1	90
Float valve (needle and seat)	9	10	1	90
Float	9	10	1	90
Float pin	9	10	1	90
Float lever	9	10	1	90
Float bowl	9	10	1	90
Main jet screw	9	10	1	90
Diaphragm	9	10	1	90
Fuel pump housing	9	10	1	90
Startup enrichment pump diaphragm	9	10	1	90
Plastic Gauge and Cap	8	10	1	80
Fuel Pickup Screen	8	10	1	80
Fuel Pickup Tube	8	10	1	80
Check valve	8	10	1	80
Diaphragm return spring	8	10	1	80
GROUP D	**RPN=<60**			
Throttle shaft	6	10	1	60
Mixture screw	6	10	1	60
Mixture screw O-ring	6	10	1	60
Main fuel nozzle	6	10	1	60
Main fuel jet	6	10	1	60
Enrichment pump spring	6	10	1	60
Enrichment pump check valve assembly	6	10	1	60
Crank seals	6	10	1	60
Piston Pin Clip	8	2	3	48
Cover gasket	9	5	1	45
Float bowl gasket	9	5	1	45
Main jet screw gasket	9	5	1	45
Pump body gasket	9	5	1	45
Enrichment pump gasket	9	5	1	45
Carburettor gasket	9	5	1	45
Reed screws	6	2	3	36
Throttle blade screw	10	2	1	20
Top carburettor cover	9	2	1	18
Float screw	9	2	1	18
Cover	9	2	1	18
Check valve retainer	8	2	1	16
Throttle blade	6	2	1	12
Restrictor plate	6	2	1	12

4.10 Summary of Design FMEA 15hp Mercury Marine Outboard

The design FMEA conducted on the 15hp Mercury Marine Outboard (model year 2002) using ethanol-blended fuels was used to rank component function failures in terms of risk priority.

The analysis found that base engine components with critical bearing surfaces were most at risk. To detect failure of these components, testing on a number of engines is recommended in order to ensure confidence in failure detection.

Components in the second highest risk category were ancillary components fundamental to engine operation. The failure of those items does not result in a severe failure, however failure will degrade engine performance. Detection of failure of these components is also via engine testing.

Components in the third highest risk category are generally components which may fail through material degradation. The potential failure of these components may produce hazardous fuel leaks. Material compatibility tests are almost certain to detect material compatibility failures.

The lowest risk category contains a variety of components. Components in this group will be monitored during testing of higher risk components.

Engine components could potentially experience function failure through the use of ethanol-blended fuel. The effects of function failure (in order of potential incidence) include:

- Lack of power
- Fuel leaks
- Engine stopping
- Rough engine operation
- Engine seizure
- Engine not starting
- Poor starting
- Throttle sticking

Lack of power, fuel leaks, engine stopping and rough engine operation have the potential to be the most common effects of component failure. The mechanisms by which these failures potentially occur are material degradation and gumming.

Proposed durability, emissions and materials testing is considered to almost certainly capture these highlighted potential failures.

5 Design FMEA - Stihl FS45 Line-trimmer

A design FMEA was conducted on a two-stroke Stihl FS45 Line-trimmer engine. This engine was considered to be representative of engines in the utility group. The FMEA exercise was limited to how components function may be impaired by using ethanol-blended fuels. The FMEA table is attached in Appendix G. A discussion of the FMEA analysis follows.

5.1 Item/ Function

The first step in conducting the FMEA was to list all engine components exposed to the E20 fuel and the components function. The list of components was generated by disassembly of the engine to allow inspection and naming of all components. The list of components and functions is shown in Appendix G.

5.2 Potential Failure Modes

Typical failure modes for the line-trimmer engine are listed in Appendix G. The failure mode relates to the failure of the component to perform the intended function.

5.3 Potential Effect(s) of Failure

Potential effects of failure are listed in Appendix G. The analysis found that many component function failures had the potential to create similar effects of failure. Potential effects of failure include:

- Lack of power
- Rough engine operation
- Fuel leaks
- Engine seizure
- Engine stopping
- Engine not starting
- Poor starting
- Throttle sticking

Figure 11 illustrates a summary of potential effects of failure and provides a percentage rating for each effect of failure. Lack of power and rough engine operation are the most common effect of potential function failure, followed by fuel leaks and engine seizure.

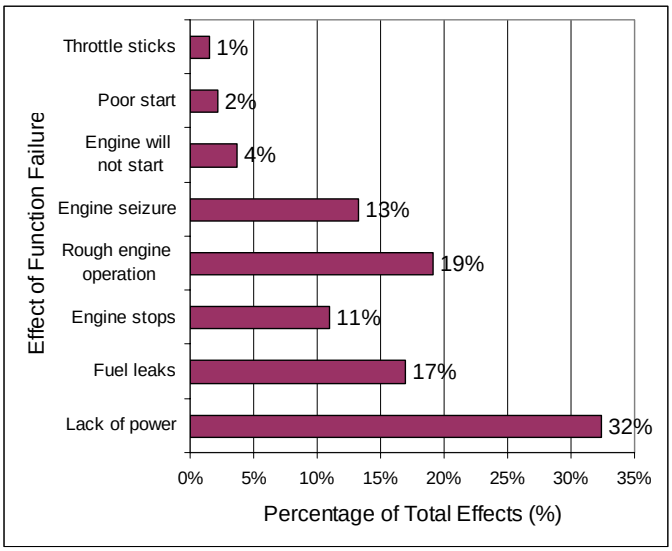

Figure 11 Effect of component function failure on engine operation

Figure 11 does not address the severity of the effect of function failure.

5.4 Severity Rating

Occurrence ratings were assigned using information outlined in section 4.4.

5.5 Potential Cause/ Mechanism of Failure

Refer to section 4.5, which contains detailed information on potential mechanisms of function failure for engines running ethanol-blended fuels.

To summarise the potential mechanisms of failure Figure 12 displays the proportion of mechanisms discussed in this analysis. This figure shows that material degradation (corrosion or perishing) is potentially the most significant function failure mechanism.

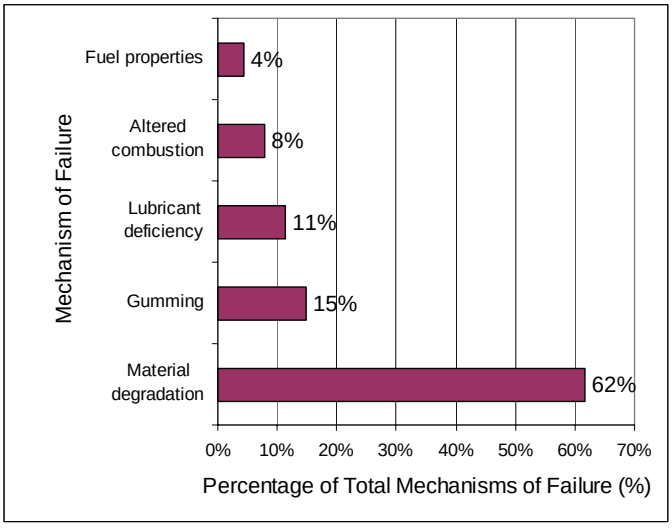

Figure 12 Percentage of total mechanism of function failure

5.6 Occurrence

Occurrence ratings were assigned using information outlined in section 4.6.

5.7 Current Design Controls

Current design controls in place for the TS45 Stihl Line-trimmer engine include durability, emissions and material compatibility testing.

5.8 Detection Rating

A detection rating of 1 (almost certain) was assigned to all engine components since component material compatibility tests and engine testing will detect component failures.

5.9 Risk Priority Number

Risk priority numbers ranged from 10 to 240. Risk priority numbers are illustrated in Figure 13.

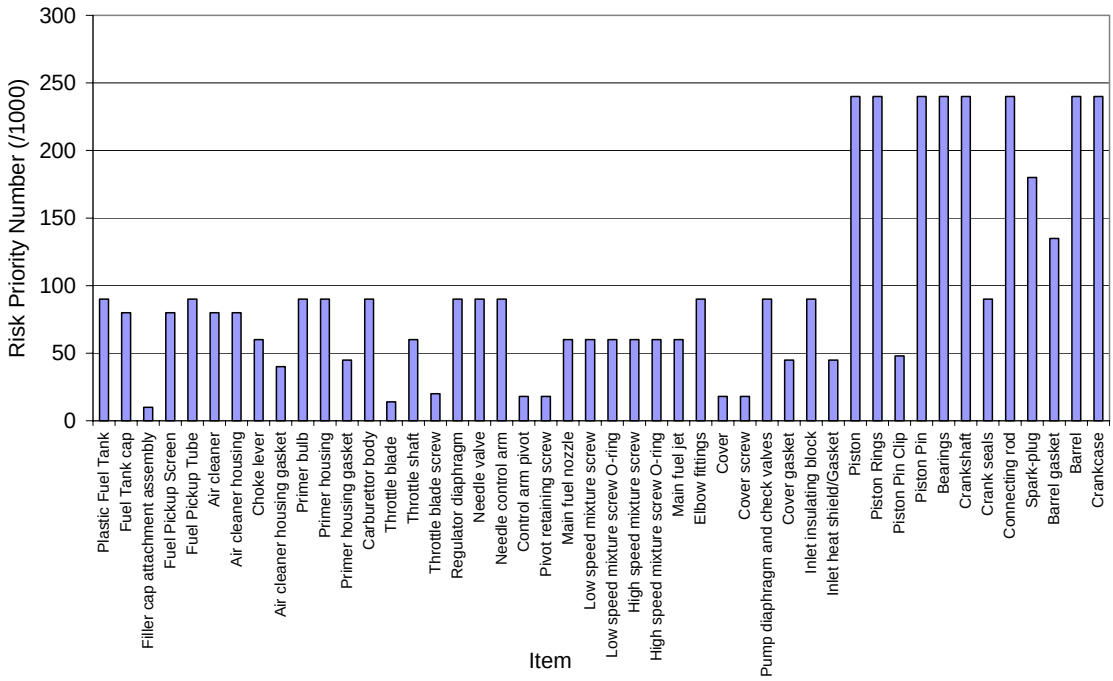

Figure 13 Risk Priority Number for components of FS45 Line-trimmer engine

The components analysed were grouped based on RPN ranking. Table 9 lists the components in RPN order and group order. Components in Group A have the highest priority for validation of function.

Group A contains base engine components (eg crankshaft, pistons and bearings). An observation that can be made is the occurrence rating for these components is 10. There is a high expectation that the failure will be detected during engine testing (detection – 3). The potential failures are a result of the relatively unknown effect of ethanol-blended fuels effect on combustion and corrosion of critical bearing surfaces in a line-trimmer engine.

Group B contains ancillary components that must be validated by engine testing (detection – 3).

Group C components are also manufactured from a variety of materials. The potential failure of the components is typically through material degradation. The failure would typically produce a fuel leak or stop the engine running (severity – 9). Material compatibility test should detect failure of these components (detection – 1)

Group D is the lowest risk category. Failure of group D components can have a variety of effects, from engine stopping to fuel leaks, however the likely occurrence of these failures ranks them low on the RPN scale.

Table 9 Line-trimmer components severity rating, occurrence rating, detection rating and risk priority number

Item	Severity rating	Occurrence rating	Detection rating	Risk priority number
GROUP A	**RPN>180**			
Piston	8	10	3	240
Piston Rings	8	10	3	240
Piston Pin	8	10	3	240
Bearings	8	10	3	240
Crankshaft	8	10	3	240
Connecting rod	8	10	3	240
Barrel	8	10	3	240
Crankcase	8	10	3	240
GROUP B	**RPN=<180**			
Spark-plug	6	10	3	180
Barrel gasket	9	5	3	135
GROUP C	**RPN=<120**			
Plastic Fuel Tank	9	10	1	90
Fuel Pickup Tube	9	10	1	90
Primer bulb	9	10	1	90
Primer housing	9	10	1	90
Carburettor body	9	10	1	90
Regulator diaphragm	9	10	1	90
Needle valve	9	10	1	90
Needle control arm	9	10	1	90
Elbow fittings	9	10	1	90
Pump diaphragm and check valves	9	10	1	90
Inlet insulating block	9	10	1	90
Crank seals	9	10	1	90
Fuel Tank cap	8	10	1	80
Fuel Pickup Screen	8	10	1	80
Air cleaner	8	10	1	80
Air cleaner housing	8	10	1	80
GROUP D	**RPN=<60**			
Choke lever	6	10	1	60
Throttle shaft	6	10	1	60
Main fuel nozzle	6	10	1	60
Low speed mixture screw	6	10	1	60
Low speed mixture screw O-ring	6	10	1	60
High speed mixture screw	6	10	1	60
High speed mixture screw O-ring	6	10	1	60
Main fuel jet	6	10	1	60
Piston Pin Clip	8	2	3	48
Primer housing gasket	9	5	1	45
Cover gasket	9	5	1	45
Inlet heat shield/Gasket	9	5	1	45
Air cleaner housing gasket	8	5	1	40
Throttle blade screw	10	2	1	20
Control arm pivot	9	2	1	18
Pivot retaining screw	9	2	1	18
Cover	9	2	1	18
Cover screw	9	2	1	18
Throttle blade	7	2	1	14
Filler cap attachment assembly	1	10	1	10

5.10 Summary of Design FMEA FS45 Stihl Line-trimmer

The design FMEA conducted on the Stihl FS45 Line-trimmer engine indicates that potential failure mechanisms are the same as those of the outboard engine as discussed in section 4.10.

The analysis confirmed that base engine components with critical bearing surfaces were most at risk of function failure. To detect failure of these components, testing on a number of engines is recommended in order to ensure confidence in failure detection

Components in the second highest risk category were components which must be evaluated by engine testing.

Components in the third highest risk category are generally components which may fail through material degradation. The potential failure of these components may produce hazardous fuel leaks. Material compatibility tests are almost certain to detect material compatibility failures.

Engine components could potentially experience function failure through the use of ethanol-blended fuel. The effects of function failure (in order of potential incidence) include:

- Lack of power
- Rough engine operation
- Fuel leaks
- Engine seizure
- Engine stopping
- Engine not starting
- Poor starting
- Throttle sticking

Lack of power, rough engine operation, fuel leaks and engine seizure have the potential to be the most common effects of component failure. The mechanisms by which these potentially occur are material degradation, gumming, lubricant deficiency and altered combustion.

Proposed durability, emissions and materials testing is considered to almost certainly capture these highlighted potential failures.

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7 Appendix A

Functional FMEA table for Aircraft engine group

POTENTIAL FAILURE MODE AND EFFECT ANALYSIS
FUNCTION FMEA FOR AIRCRAFT APPLICATION

Prepared by JRM

Date: 10/10/2002 Core Team: JRM, GBB, LAG, NC1, MJT, DFN

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Cold Starting -to commence engine operation	Engine fails to start Start time is excessive Engine starts then stalls	Equipment cannot be used	8	Insufficient startup enrichment Fuel volatility low at ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Gumming High latent heat of vaporisation of fuel Failed decompression valve Foulled sparkplug Ignition energy insufficient Failed engine components Low compression ratio No fuel flow Poor fuel quality Unsuitable airflow Flooded engine Unsuitable spark advance Fuel pooling Fuel distribution (cyl to cyl)	10	no controls in place	10	800

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Hot Starting -to commence engine operation	Engine fails to start Start time is excessive Engine starts then stalls	Equipment cannot be used till cold start is possible Engine may not restart during flight if required	10	Insufficient startup enrichment Fuel contaminated (eg water) Vapour lock in fuel system blocking fuel flow Fuel supply blockage Operation outside ignitable AFR range Failed decompression valve Sparkplug heat range unsuitable Gumming High latent heat of vaporisation of fuel Foulled sparkplug Failed engine components No fuel flow Poor fuel quality Insufficient airflow Flooded engine Unsuitable spark advance	10	no controls in place	10	1000
Warmup -ensure engine operation when not at operating temperature	Engine stalls Engine power output low Engine not efficient Rough engine operation	Engine cannot drive equipment Excesive emissions Poor fuel consumption Engine may need to be completely warm before use	10	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range from hot to cold Fuel system or throttle icing Unsuitable ignition timing Poor combustion Sparkplug heat range unsuitable Gumming	10	no controls in place	10	1000

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Idle -operation at lowest engine power while driving equipment	Engine stalls Rough engine operation Inefficent operation	Excessive emissions Poor fuel consumption	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Unsuitable ignition timing Poor combustion Stuck exhaust valve Sparkplug heat range unsuitable Gumming Foulled sparkplug Low compression ratio No fuel flow Poor fuel quality Insufficient airflow Flooded engine Fuel system or throttle icing Unsuitable spark advance	8	no controls in place	10	560
Part Load -engine operating point between idle and full load	Engine stalls Engine seizure Rough engine operation Inefficent operation	Failure of exhaust components (eg catalyst) Poor fuel consumption Excessive emissions Aircraft cannot maintain altitude	10	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Gumming Foulled sparkplug Low compression ratio No fuel flow Poor fuel quality Insufficient airflow Flooded engine Fuel system or throttle icing Unsuitable spark advance	10	no controls in place	10	1000

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Full Load -engine operating point full throttle	Engine stalls Engine seizure Rough engine operation Inefficent operation Lack of power	Failure of exhaust components (eg catalyst) Poor fuel consumption Excessive emissions Engine cannot drive equipment Aircraft cannot maintain altitude Aircraft cannot climb to higher altitude	10	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Gumming Foulled sparkplug Excessive emissions Engine failure Unsuitable spark advance Lack of power	10	no controls in place	10	1000
Speed Control -engine operation for constant speed varying load	Engine damage Inefficient operation naccurate control Poor control to nominal speed Engine exceed maximum engine speed	Engine cannot drive equipment Erratic engine operation	10	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Gumming	8	no controls in place	10	800
Load Control - torque backup	Engine Stalls Inaccurate control Engine cannot maintain load Engine damage	Engine cannot drive equipment Erratic engine operation Aircraft cannot maintain altitude	10	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Gumming	8	no controls in place	10	800

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Overspeed -function to limit maximum engine speed	Engine failure Poor speed control Engine overspeed	Engine damage	10	Operaton lean of set point (high speed mixture control) Ignition control defective Governer control defective Gumming Ignitable AFR range	10	no controls in place	10	1000
Shutdown -cease engine operation	Ignition kill does not stop engine	Engine fails to stop Engine damage upon shutdown	10	Pre-ignition from hot chamber surfaces Fault with ignition kill Gumming	10	no controls in place	10	1000

8 Appendix B

Functional FMEA table for Utility engine group

POTENTIAL FAILURE MODE AND EFFECT ANALYSIS

FUNCTION FMEA FOR UTILITY APPLICATION

Prepared by JRM

Date: 10/10/2002Core Team: JRM, GBB, LAG, NC1, MJT, DFN

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Cold Starting -to commence engine operation	Engine fails to start Start time is excessive Engine starts then stalls	Equipment cannot be used	7	Insufficient startup enrichment Fuel volatility low at ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Gumming High latent heat of vaporisation of fuel Failed decompression valve Foulled sparkplug Ignition energy insufficient Failed engine components Low compression ratio No fuel flow Poor fuel quality Unsuitable airflow Flooded engine Unsuitable spark advance Fuel pooling Fuel distribution (cyl to cyl)	10	Engine Testing	1	70

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Hot Starting -to commence engine operation	Engine fails to start Start time is excessive Engine starts then stalls	Equipment cannot be used till cold start is possible	7	Insufficient startup enrichment Fuel contaminated (eg water) Vapour lock in fuel system blocking fuel flow Fuel supply blockage Operation outside ignitable AFR range Failed decompression valve Sparkplug heat range unsuitable Gumming High latent heat of vaporisation of fuel Foulled sparkplug Failed ignition control module Failed engine components No fuel flow Poor fuel quality Insufficient airflow Flooded engine Unsuitable spark advance	10	Engine Testing	1	70
Warmup -ensure engine operation when not at operating temperature	Engine stalls Engine power output low Engine not efficient Rough engine operation	Engine cannot drive equipment Excesive emissions Poor fuel consumption	6	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range from hot to cold Fuel system or throttle icing Unsuitable ignition timing Poor combustion Sparkplug heat range unsuitable Gumming	8	Engine Testing	1	48

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Idle -operation at lowest engine power while driving equipment	Engine stalls Rough engine operation Inefficent operation	Excessive emissions Poor fuel consumption	6	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Unsuitable ignition timing Poor combustion Stuck exhaust valve Sparkplug heat range unsuitable Gumming Foulled sparkplug Low compression ratio No fuel flow Poor fuel quality Insufficient airflow Flooded engine Fuel system or throttle icing Unsuitable spark advance	8	Engine Testing	2	96
Part Load -engine operating point between idle and full load	Engine stalls Engine seizure Rough engine operation Inefficent operation	Failure of exhaust components (eg catalyst) Poor fuel consumption Excessive emissions	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Stuck exhaust valve Gumming Foulled sparkplug Low compression ratio No fuel flow Poor fuel quality Insufficient airflow Flooded engine Fuel system or throttle icing Unsuitable spark advance	8	Engine Testing	10	560

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Full Load -engine operating point full throttle	Engine stalls Engine seizure Rough engine operation Inefficent operation Lack of power	Failure of exhaust components (eg catalyst) Poor fuel consumption Excessive emissions Engine cannot drive equipment	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Stuck exhaust valve Gumming Foulled sparkplug Excessive emissions Engine failure Unsuitable spark advance Lack of power	10	Engine Testing	1	70
Speed Control -engine operation for constant speed varying load	Engine damage Inefficient operation naccurate control Poor control to nominal speed Engine exceed maximum engine speed	Engine cannot drive equipment Erratic engine operation Electrical equipment may be damaged (engine driving a generator)	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Gumming	8	no controls in place	10	560
Load Control - torque backup	Engine Stalls Inaccurate control Engine cannot maintain load Engine damage	Engine cannot drive equipment Erratic engine operation	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Gumming	8	no controls in place	10	560

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Overspeed -function to limit maximum engine speed	Engine failure Poor speed control Engine overspeed	Operator injury Engine damage	10	Operaton lean of set point (high speed mixture control) Ignition control defective Governer control defective Gumming Ignitable AFR range	10	Engine Testing	1	100
Overrun operation -engine operation when device drives engine	Engine continues to drive Overun condition irregular (shunting) Overun condition altered	Engine damage during overun (pre-ignition)	2	Pre-ignition from hot chamber surfaces Fuel supply surge Gumming	6	no controls in place	10	120
Shutdown -cease engine operation	Ignition kill does not stop engine	Engine fails to stop Engine damage upon shutdown	10	Pre-ignition from hot chamber surfaces Fault with ignition kill Gumming	10	Engine Testing	1	100

9 Appendix C

Functional FMEA table for Marine engine group

POTENTIAL FAILURE MODE AND EFFECT ANALYSIS
FUNCTION FMEA FOR MARINE APPLICATION

Prepared by JRM

Date: 10/10/2002

Core Team: JRM, GBB, LAG, NC1, MJT, DFN

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Cold Starting -to commence engine operation	Engine fails to start Start time is excessive Engine starts then stalls	Equipment cannot be used	8	Insufficient startup enrichment Fuel volatility low at ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Gumming High latent heat of vaporisation of fuel Failed decompression valve Foulled sparkplug Ignition energy insufficient Failed engine components Low compression ratio No fuel flow Poor fuel quality Unsuitable airflow Flooded engine Unsuitable spark advance Fuel pooling Fuel distribution (cyl to cyl)	10	Engine Testing	1	80

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Hot Starting -to commence engine operation	Engine fails to start Start time is excessive Engine starts then stalls	Equipment cannot be used till cold start is possible	8	Insufficient startup enrichment Fuel contaminated (eg water) Vapour lock in fuel system blocking fuel flow Fuel supply blockage Operation outside ignitable AFR range Failed decompression valve Sparkplug heat range unsuitable Gumming High latent heat of vaporisation of fuel Foulled sparkplug Failed ignition control module Failed engine components No fuel flow Poor fuel quality Insufficient airflow Flooded engine Unsuitable spark advance	10	Engine Testing	1	80
Warmup -ensure engine operation when not at operating temperature	Engine stalls Engine power output low Engine not efficient Rough engine operation	Engine cannot drive equipment Excesive emissions Poor fuel consumption	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range from hot to cold Fuel system or throttle icing Unsuitable ignition timing Poor combustion Sparkplug heat range unsuitable Gumming	8	Engine Testing	1	56

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Idle -operation at lowest engine power while driving equipment	Engine stalls Rough engine operation Inefficent operation	Excessive emissions Poor fuel consumption	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Unsuitable ignition timing Poor combustion Stuck exhaust valve Sparkplug heat range unsuitable Gumming Foulled sparkplug Low compression ratio No fuel flow Poor fuel quality Insufficient airflow Flooded engine Fuel system or throttle icing Unsuitable spark advance	8	Engine Testing	1	56
Part Load -engine operating point between idle and full load	Engine stalls Engine seizure Rough engine operation Inefficent operation	Failure of exhaust components (eg catalyst) Poor fuel consumption Excessive emissions Vessel will not maintain planing speed	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Stuck exhaust valve Gumming Foulled sparkplug Low compression ratio No fuel flow Poor fuel quality Insufficient airflow Flooded engine Fuel system or throttle icing Unsuitable spark advance	8	no controls in place	10	560

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Full Load -engine operating point full throttle	Engine stalls Engine seizure Rough engine operation Inefficent operation Lack of power	Failure of exhaust components (eg catalyst) Poor fuel consumption Excessive emissions Engine cannot drive equipment Vessel will not reach planing speed	9	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Stuck exhaust valve Gumming Foulled sparkplug Excessive emissions Engine failure Unsuitable spark advance Lack of power	10	Engine Testing	1	90
Speed Control -engine operation for constant speed varying load	Engine damage Inefficient operation naccurate control Poor control to nominal speed Engine exceed maximum engine speed	Engine cannot drive equipment Erratic engine operation Trolling not possible	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Gumming	8	no controls in place	10	560
Load Control - torque backup	Engine Stalls Inaccurate control Engine cannot maintain load Engine damage	Engine cannot drive equipment Erratic engine operation	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Gumming	8	no controls in place	10	560

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Overspeed -function to limit maximum engine speed	Engine failure Poor speed control Engine overspeed	Engine damage	4	Operaton lean of set point (high speed mixture control) Ignition control defective Governer control defective Gumming Ignitable AFR range	10	no controls in place	10	400
Shutdown -cease engine operation	Ignition kill does not stop engine	Engine fails to stop Engine damage upon shutdown	10	Pre-ignition from hot chamber surfaces Fault with ignition kill Gumming	10	Engine Testing	1	100

10 Appendix D

Functional FMEA table for Vehicle engine group

POTENTIAL FAILURE MODE AND EFFECT ANALYSIS
FUNCTION FMEA FOR VEHICLE APPLICATION (eg Snowmobile, Motorcycle)

Prepared by JRM

Date: 10/10/2002

Core Team: JRM, GBB, LAG, NC1, MJT, DFN

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Cold Starting -to commence engine operation	Engine fails to start Start time is excessive Engine starts then stalls	Equipment cannot be used	8	Insufficient startup enrichment Fuel volatility low at ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Gumming High latent heat of vaporisation of fuel Failed decompression valve Foulled sparkplug Ignition energy insufficient Failed engine components Low compression ratio No fuel flow Poor fuel quality Unsuitable airflow Flooded engine Unsuitable spark advance Fuel pooling Fuel distribution (cyl to cyl)	10	no controls in place	10	800

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Hot Starting -to commence engine operation	Engine fails to start Start time is excessive Engine starts then stalls	Equipment cannot be used till cold start is possible	8	Insufficient startup enrichment Fuel contaminated (eg water) Vapour lock in fuel system blocking fuel flow Fuel supply blockage Operation outside ignitable AFR range Failed decompression valve Sparkplug heat range unsuitable Gumming High latent heat of vaporisation of fuel Foulled sparkplug Failed ignition control module Failed engine components No fuel flow Poor fuel quality Insufficient airflow Flooded engine Unsuitable spark advance	10	no controls in place	10	800
Warmup -ensure engine operation when not at operating temperature	Engine stalls Engine power output low Engine not efficient Rough engine operation	Engine cannot drive equipment Excesive emissions Poor fuel consumption	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range from hot to cold Fuel system or throttle icing Unsuitable ignition timing Poor combustion Sparkplug heat range unsuitable Gumming	8	no controls in place	10	560

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Idle -operation at lowest engine power while driving equipment	Engine stalls Rough engine operation Inefficent operation	Excessive emissions Poor fuel consumption	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Unsuitable ignition timing Poor combustion Stuck exhaust valve Sparkplug heat range unsuitable Gumming Foulled sparkplug Low compression ratio No fuel flow Poor fuel quality Insufficient airflow Flooded engine Fuel system or throttle icing Unsuitable spark advance	8	no controls in place	10	560
Part Load -engine operating point between idle and full load	Engine stalls Engine seizure Rough engine operation Inefficent operation	Failure of exhaust components (eg catalyst) Poor fuel consumption Excessive emissions	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Stuck exhaust valve Gumming Foulled sparkplug Low compression ratio No fuel flow Poor fuel quality Insufficient airflow Flooded engine Fuel system or throttle icing Unsuitable spark advance	8	no controls in place	10	560

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Full Load -engine operating point full throttle	Engine stalls Engine seizure Rough engine operation Inefficent operation Lack of power	Failure of exhaust components (eg catalyst) Poor fuel consumption Excessive emissions Engine cannot drive equipment	9	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Stuck exhaust valve Gumming Foulled sparkplug Excessive emissions Engine failure Unsuitable spark advance Lack of power	10	no controls in place	10	900
Speed Control -engine operation for constant speed varying load	Engine damage Inefficient operation naccurate control Poor control to nominal speed Engine exceed maximum engine speed	Engine cannot drive equipment Erratic engine operation	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Gumming	8	no controls in place	10	560
Load Control - torque backup	Engine Stalls Inaccurate control Engine cannot maintain load Engine damage	Engine cannot drive equipment Erratic engine operation	7	Fuel volatility to low for ambient temperature Fuel contaminated (eg water) Fuel supply blockage Operation outside ignitable AFR range Fuel system or throttle icing Piston/bore failure through knock/preignition Unsuitable ignition timing Poor combustion Gumming	8	no controls in place	10	560

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Overspeed -function to limit maximum engine speed	Engine failure Poor speed control Engine overspeed	Engine damage	4	Operaton lean of set point (high speed mixture control) Ignition control defective Governer control defective Gumming Ignitable AFR range	10	no controls in place	10	400
Overrun operation -engine operation when device drives engine	Engine continues to drive Overun condition irregular (shunting) Overun condition altered	Engine damage during overun (pre-ignition)	6	Pre-ignition from hot chamber surfaces Fuel supply surge Gumming	6	no controls in place	10	360
Shutdown -cease engine operation	Ignition kill does not stop engine	Engine fails to stop Engine damage upon shutdown	10	Pre-ignition from hot chamber surfaces Fault with ignition kill Gumming	10	no controls in place	10	1000

11 Appendix E

Design FMEA table for 15hp Mercury Marine Outboard

DESIGN FAILURE MODE AND EFFECT ANALYSIS
DESIGN FMEA FOR MERCURY TWO STROKE 15HP OUTBOARD ENGINE 2002 MODEL YEAR

Prepared by JRM

Date: 10/10/2002

Core Team: JRM, PTG, HWC, LAG

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Plastic Fuel Tank	**contains fuel**	**fuel leak**	**fuel spill into vessel or waterway**	**9**	**hole in tank - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	prevents contamination of fuel	fuel contaminated	engine lacks power rough engine operation	8	hole in tank - material degradation	10	Material Compatibility Tests, Engine Testing	1	80
Plastic Gauge and Cap	seals tank	leaks fuel contamination	engine lacks power rough engine operation	6	cap distorted, hole in cap - material degradation	10	Material Compatibility Tests, Engine Testing	1	60
	displays fuel level	shows incorrect level	engines stops	2	mechanism jammed, float sinks - material degradation	10	Material Compatibility Tests, Engine Testing	1	20
	vents tank	blockage vapour release	engine stops excessive evaporative emissions	5	vent blocked or distorted - material degradation	10	Material Compatibility Tests, Engine Testing	1	50
	allows tank to be filled	**cap cannot be removed**	**tank cannot be filled - engine stops**	**8**	**cap distorted, stuck to tank - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**80**
Fuel Pickup Screen	prevents debris entering fuel line	debris passes filter	blockage of fuel lines and primer bulb mechanism - engine stops	5	screen material attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	50
	transfer fuel	**blockage**	**engine stops lack of power**	**8**	**screen material attacked by fuel - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**80**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Fuel Pickup Tube	**transfer of fuel**	**blockage air leak**	**engine stops lack of power**	**8**	**tube attacked by fuel, blocking flow - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**80**
	holds pickup screen	screen falls off tube	blockage of fuel lines - lack of power	5	tube attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	50
Top of Pickup	**transfer of fuel**	**blockage air leak fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**attacked by fuel, material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	retains fuel hose	fuel hoses detaches	fuel leaks engine stops	9	pick up attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	90
	seals against fuel tank	leaks	tank vented incorrectly - engine stops fuel leaks contaminates fuel tank - rough engine operation	4	top of pickup distorts or loses rigidity, small chance of leak since at top of tank - material degradation	10	Material Compatibility Tests, Engine Testing	1	40
Connector - Fuel tank to fuel hose	**transfer of fuel**	**blockage air leak fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**connector attacked by fuel, distorts blocking flow, hole is formed allowing air or fuel leak - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	retains fuel tubing	fuel hoses detaches	fuel leaks engine stops	9	connector or hose attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	90
Fuel Hose	**transfer of fuel**	**blockage air leak fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**attacked by fuel, distorts blocking flow, hole is formed allowing air or fuel leak - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	maintain connection with fuel connector	fuel hoses detaches	fuel leaks engine stops	9	fuel hose attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	90

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Check valve assembly inlet and outlet	directs fuel flow	flow direction not controlled blockage	primer bulb cannot prime fuel system engine will not start	6	check valve elastomer is attacked by fuel - material degradation gumming	10	Material Compatibility Tests, Engine Testing	1	60
	secures primer bulb	primer bulb detaches	fuel leaks engine stops	9	fitting corrodes is attacked by fuel - Corrison or material degradation	10	Material Compatibility Tests, Engine Testing	1	90
	retains fuel hose	fuel hoses detaches	fuel leaks engine stops	9	fitting corrodes is attacked by fuel - Corrison or material degradation	10	Material Compatibility Tests, Engine Testing	1	90
	transfer of fuel	**blockage air leak fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**check valve elastomer is attacked by fuel blocking flow path - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Primer bulb	pump element to prime fuel system	fails to pump fuel	engine will eventually start	6	bulb is attacked by fuel, become to hard to squeeze or hole is formed and bulb cannot hold pressure - material degradation	10	Material Compatibility Tests, Engine Testing	1	60
	transfer of fuel	**blockage air leak fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**bulb is attacked by fuel, hole is formed and bulb cannot hold pressure, bulb distorts blocking flow path - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Tank fuel connector	**transfer of fuel**	**blockage air leak fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**connector is attacked by fuel, hole is formed or material distorts blocking flow path - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	retains fuel hose	fuel hoses detaches	fuel leaks engine stops	9	connector is attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	90
	seals when disconnected	does not seal when disconnected	fuel leak fuel line empties	1	seal surfaces are attacked by fuel -material degradation	10	Material Compatibility Tests, Engine Testing	1	10
Engine fuel connector	**transfer of fuel**	**blockage air leak fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**connector is attacked by fuel, hole is formed or material distorts blocking flow path - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	retains fuel hose	fuel hoses detaches	fuel leaks	9	connector or hose is attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	90
	seals when disconnected	does not seal when disconnected	fuel leak fuel line empties	1	seal surfaces are attacked by fuel -material degradation	10	Material Compatibility Tests, Engine Testing	1	10

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Fuel filter assembly	prevents debris entering fuel line	debris enters fuel lines and carburettor	fuel blockages lack of power	6	screen material attacked by fuel - material degradation	10	Material Compatibility Testing	1	60
	acts as water trap	water enters fuel lines and carburettor	corrosion of components	8	water trap fills with water or phase separation - fuel properties	2	Engine Testing	3	48
	displays water level	water level cannot be seen	water enters fuel lines and carburettor - engine stops	1	material is attacked by fuel and loses translucency - material degradation	10	Material Compatibility Tests, Engine Testing	1	10
	transfer of fuel	**blockage air leak fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**assembly is attacked by fuel, hole is formed or material distorts blocking flow path - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	retains fuel tubing	fuel hoses detaches	fuel leaks engine stops	9	assembly or hose is attacked by fuel, hole is formed or material distorts blocking flow path - material degradation	10	Material Compatibility Tests, Engine Testing	1	90
Fuel hose	**transfer of fuel**	**blockage air leak fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**hose is attacked by fuel, hole is formed or material distorts blocking flow path - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	maintain connection with fuel connector	fuel hoses detaches	fuel leaks engine stops	9	fuel hose attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	90
Carburettor body	housing for components	components not located correctly	fuel metering affected	8	corrosion of materials retaining components - material degradation	10	Material Compatibility Tests, Engine Testing	1	80
	transfer of fuel	**blockage fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**fuel attacks material, corrosion blocks flow path - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	transfer of air	air flow blocked	lack of power	6	air flow blocked by corrosion or deposits - material degradation, fuel properties	2	Material Compatibility Tests, Engine Testing	1	12
	mixing of fuel and air	air and fuel not mixed	rough engine operation lack of power	6	air or fuel flow blocked or altered, fuel does not atomise or vaporise - material degradation fuel properties gumming	10	Material Compatibility Tests, Engine Testing	1	60

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Throttle blade	**controls airflow**	**incorrect airflow control**	**lack of power poor driveability - rough engine operation**	**6**	**throttle blade corrodes, sticks to carb body - material degradation**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**12**
Throttle shaft	actuator for throttle blade	throttle blade cannot be actuated	lack of power stuck at wide open throttle	10	throttle shaft corrodes, sticks to carb body - material degradation gumming	4	Material Compatibility Tests, Engine Testing	1	40
	seal against carburettor body	**air leak into carburettor**	**rough engine operation lack of power**	**6**	**throttle shaft or carb body corrode - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Throttle blade screw	**secures throttle blade to throttle shaft**	**throttle blade not secured**	**throttle sticks during operation**	**10**	**screw corrodes to failure - material degradation**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**20**
Mixture screw	**mixture adjustment**	**fuel air mixture cannot be adjusted**	**rough engine operation**	**6**	**mixture screw corrodes altering mixture strength - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Mixture screw O-ring	**seals air and fuel**	**fuel leak air leak**	**rough engine operation**	**6**	**elastomer attacked by fuel - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Top carburettor cover	**supports gasket**	**does not support gasket**	**fuel leak**	**9**	**supports gasket, if gasket seal fuel, fuel has no effect on cover**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**18**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Cover gasket	**seals fuel and air**	**does not seal**	**fuel leak air leak - rough engine operation**	**9**	**fuel attacks gasket - material degradation**	**5**	**Material Compatibility Tests, Engine Testing**	**1**	**45**
	prevents ingress of contaminates	contanimates enter carburettor	fuel metering affected rough engine operation	6	fuel attacks gasket - material degradation	5	Material Compatibility Tests, Engine Testing	1	18
Fuel gallery plug	**seals fuel gallery**	**fails for seal fuel gallery**	**fuel leak**	**9**	**fuel attacks gallery plug - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Main fuel nozzle	**mixes fuel and air**	**fuel and air do not mix correctly**	**rough engine operation lack of power**	**6**	**air or fuel flow blocked or altered, fuel does not atomise or vapourise - material degradation fuel properties gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Main fuel jet	**metering fuel**	**fuel not metered correctly**	**rough engine operation lack of power**	**6**	**fuel jet corrodes altering metering - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Float valve (needle and seat)	**controls fuel flow**	**fuel flow not controlled**	**float level incorrect rough engine operation lack of power fuel leak**	**9**	**needle and seat corrode - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Float	**regulates fuel level**	**fuel level incorrect**	**rough engine operation lack of power fuel leak**	**9**	**fuel attacks float - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Float pin	**pivots float lever**	**float cannot move**	**fuel level incorrect rough engine operation lack of power fuel leak**	**9**	**pin corrodes and lever sticks - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Float lever	**actuates needle valve**	**needle valve not actuated**	**fuel level incorrect rough engine operation lack of power fuel leak**	**9**	**lever corrodes sticks - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Float screw	**retains float pin**	**float pin not retained**	**fuel level incorrect fuel leak**	**9**	**screw corrodes to failure - material degradation**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**18**
Float bowl gasket	**seals fuel**	**does not seal**	**fuel leak**	**9**	**fuel attacks gasket - material degradation**	**5**	**Material Compatibility Tests, Engine Testing**	**1**	**45**
Float bowl	**contains fuel**	**does not contain fuel**	**fuel leak**	**9**	**fuel attacks material forming hole - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Main jet screw	allows access to main jet	fails to allow access	cannot be removed	1	corrosion of screw - material degradation	10	Material Compatibility Tests, Engine Testing	1	10
	seals float bowl	**does not seal**	**fuel leak**	**9**	**corrsion of material to failure - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Main jet screw gasket	**seals fuel**	**does not seal**	**fuel leak**	**9**	**corrsion of material to failure - material degradation**	**5**	**Material Compatibility Tests, Engine Testing**	**1**	**45**
Pump body gasket	**seals fuel and air**	**does not seal**	**fuel leak air leak - rough engine operation**	**9**	**fuel attacks gasket - material degradation**	**5**	**Material Compatibility Tests, Engine Testing**	**1**	**45**
Diaphragm	pumping element	does not pump	lack of power engine stops	8	diaphragm elastomer is attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	80
	seals c/case pumping air and fuel	**does not seal**	**fuel may leak into crankcase fuel supply may pressurise and engine will stop**	**9**	**diaphragm elastomer is attacked by fuel - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Check valve retainer	**retains check valve elements**	**check valve not retained**	**lack of power engine stops**	**8**	**corrsion of material to failure - material degradation**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**16**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Check valve	**directs fuel flow**	**flow direction not controlled blockage**	**lack of power engine stops**	**8**	**corrsion of material to failure - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**80**
Fuel pump housing	houses pump components	pump components not located correctly	lack of power engine stops	8	corrosion of materials reatining components - material degradation	10	Material Compatibility Tests, Engine Testing	1	80
	transfer of fuel	**blockage fuel leak**	**engine stops lack of power fuel spill into vessel and waterway**	**9**	**fuel attacks material, corrosion blocks flow path - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	retains fuel hose	fuel hoses detaches	fuel leaks engine stops	9	fuel attacks connection - material degradation	10	Material Compatibility Tests, Engine Testing	1	90
Diaphragm return spring	**returns pump diaphragm to rest position**	**does not return diaphragm to rest position**	**lack of power engine stops**	**8**	**fuel corrodes spring - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**80**
Cover	**supports diaphragm edges**	**diaphragm not supported**	**fuel leak**	**9**	**supports gasket, if gasket seal fuel, fuel has no effect on cover**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**18**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Startup enrichment pump diaphragm	pumps fuel	fails to pump fuel	engine will eventually start	6	diaphragm elastomer is attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	60
	seals fuel	**fails to seal fuel**	**fuel leak**	**9**	**diaphragm elastomer is attacked by fuel - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Enrichment pump gasket	**seals fuel**	**fails to seal fuel**	**fuel leak**	**9**	**fuel attacks gasket - material degradation**	**5**	**Material Compatibility Tests, Engine Testing**	**1**	**45**
Enrichment pump spring	**returns diaphragm to position**	**fails to return pump diaphragm to rest position**	**engine will eventually start**	**6**	**spring corrodes to failure - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Enrichment pump check valve assembly	**directs fuel flow**	**fails to direct fuel flow**	**engine will eventually start**	**6**	**check valve elastomer is attacked by fuel - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Carburettor gasket	seals air	fails to seal air	rough engine operation	6	fuel attacks gasket - material degradation	5	Material Compatibility Tests, Engine Testing	1	30
	seals air fuel mixture	**fails to seal air fuel mixture**	**fuel leak**	**9**	**fuel attacks gasket - material degradation**	**5**	**Material Compatibility Tests, Engine Testing**	**1**	**45**
Restrictor plate	**limits engine airflow**	**fails to limit airflow**	**rough engine operation**	**6**	**fuel attacks restrictor plate increasing aperture - material degradation**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**12**
Reed block	locates reeds	fails to locate reeds	rough engine operation lack of power	6	fuel attacks reed block material - material degradation	2	Material Compatibility Tests, Engine Testing	1	12
	transfer of fuel air mixture	fails to transfer fuel air mixture	lack of power	6	fuel attacks reed block material - material degradation	2	Engine Testing	3	36
	seals fuel air mixture (with reeds)	fails to seal	lack of power rough engine operation	6	fuel attacks reed seat material - material degradation gumming	10	Engine Testing	3	180
	seals fuel air mixture (against cylinder block)	**fails to seal**	**lack of power** **rough engine operation**	**6**	**fuel attacks reed seat material - material degradation** **gumming**	**10**	**Engine Testing**	**3**	**180**
Reeds	directs flow of fuel air mixture	fails to direct fuel air mixture flow	lack of power rough engine operation engine will not start	6	fuel attacks reeds - material degradation gumming	10	Engine Testing	3	180
	seals fuel air mixture (with reed plate)	**fails to seal fuel air mixture**	**lack of power** **rough engine operation** **engine will not start**	**6**	**fuel attacks reeds - material degradation** **gumming**	**10**	**Engine Testing**	**3**	**180**
Reed screws	**retains reeds**	**fails to retain reeds**	**lack of power** **rough engine operation** **engine will not start**	**6**	**fuel attacks screws to failure - material degradation**	**2**	**Engine Testing**	**3**	**36**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Crankshaft	**provides bearing surfaces**	**fails to proide suitable bearing surface**	**lack of power engine seizure**	**8**	**corrosion of bearing surfaces, increased friction - material degradation lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**
	provides sealing surfaces	fails to provide sealing surface	lack of power rough engine operation	6	corrosion of seal surface on crank - material degradation	10	Engine Testing	3	180
	locates major components	fails to locate major components	engine seizure	8	Corrosion of crank to failure - material degradation	2	Engine Testing	3	48
	converts connecting rod loads to torque	fails to convert connecting rod load to torque	lack of power	6	Corrosion of crank to failure - material degradation	2	Engine Testing	3	36
Connecting rods	**provides bearing surfaces**	**fails to proide suitable bearing surface**	**lack of power engine seizure**	**8**	**corrosion of bearing surfaces, increased friction - material degradation lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**
	transmit piston loads to crankshaft	fails to transmit pistons loads to crankshaft	lack of power	6	Corrosion of rod to failure - material degradation	2	Engine Testing	3	36
Bearings	transmit load between bearing surfaces	fails to transmit load between bearing surfaces	lack of power	6	corrosion of bearing surfaces, increased friction - material degradation lubricant deficiency	10	Engine Testing	3	180
	allow relative movement between surfaces	**fails to allow relative movement**	**lack of power engine seizure**	**8**	**corrosion of bearing surfaces, increased friction - material degradation lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**
Crank seals	**seals fuel air mixture**	**fails to seal**	**fuel leak lack of power rough engine operation**	**6**	**fuel attacks seal - material degradation lubricant deficiency**	**5**	**Engine Testing**	**1**	**30**
Piston	**compress air fuel mixture**	**fails to compress mixture**	**engine will not start lack of power rough engine operation engine seizure**	**8**	**hole in piston from - altered combustion**	**10**	**Engine Testing**	**3**	**240**
	controls opening and closing of ports	fails to control opening and closing of ports	engine will not start	8	erosion of piston crown will alter port timing - altered combustion	2	Engine Testing	3	48
	provides a bearing surface	fails to provide a bearing surface	engine seizure	8	corrosion of bearing surfaces - material degradation lubricant deficiency	10	Engine Testing	3	240
	transmit gas pressure loads to the connecting rod	fails to transmit gas loads to the connecting rod	lack of power engine seizure	8	hole in piston, piston seizure, high friction - altered combustion lubricant deficiency	10	Engine Testing	3	240

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Piston Rings	seals between cylinder volume and crankcase	fails to seal	lack of power hard to start	6	ring wear, ring jacking, ring stick - combustion temperaures lubricant deficiency	10	Engine Testing	3	180
	transfers heat	**fails to transfer heat**	**lack of power** **knock** **piston overheats, engine seizure**	**8**	**ring wear, ring jacking, ring stick - altered combustion** **lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**
Piston Pin Clip	**retains piston pin**	**fails to retain piston pin**	**engine seizure**	**8**	**corrosion of pin clip to failure - material degradation**	**2**	**engine Testing**	**3**	**48**
Piston Pin	connects connecting rod and piston	fails to connect connecting rod and piston	engine seizure	8	corrosion of pin - material degradation	2	Engine Testing	3	48
	provides bearing surface	**fails to provide a bearing surface**	**engine seizure**	**8**	**corrosion of pin - material degradation** **lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**
Cylinder block	housing for engine components	fails to house engine components	engine seizure	8	corrosion of materials reatining components - material degradation	1	Engine Testing	3	24
	provides bearing surface	**fails to provide bearing surface**	**engine seizure**	**8**	**altered combustion** **lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**
	transfers fresh charge	fails to transfer fresh charge	rough engine operation lack of power	6	transfer port is blocked by deposits from exhaust gas - fuel properties altered combustion lubricant deficiency	2	Engine Testing	3	36
	transfers exhaust gas	fails to transfer fresh charge	rough engine operation lack of power	6	exhaust port is blocked by deposits from exhaust gas - fuel properties altered combustion lubricant deficiency	2	Engine Testing	3	36
	contains fresh charge	fails to contain fresh charge	fuel air mixture leaks lack of power rough engine operation	9	cylinder block corrodes and a hole is formed in crankcase - material degradation	6	Engine Testing	3	162
	retains carburettor	fails to retain carburettor	engine will not start	8	cylinder block corrodes damaging mounting face - material degradation	2	Material Compatibility Tests, Engine Testing	3	48

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Spark-plug	**ignites fresh charge**	**fails to ignite fresh charge**	**rough engine operation lack of power engine will not start**	**6**	**foulling, incorrect heat range electrodes - altered combustion**	**10**	**Engine Testing**	**3**	**180**

12 Appendix F

Figures of 15hp Mercury Marine Outboard Engine

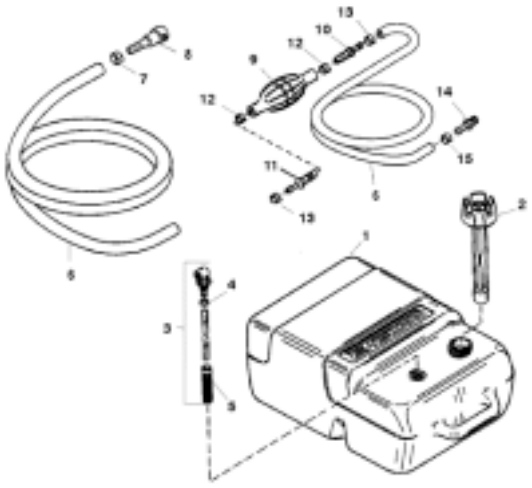

Figure 14 Fuel tank assembly

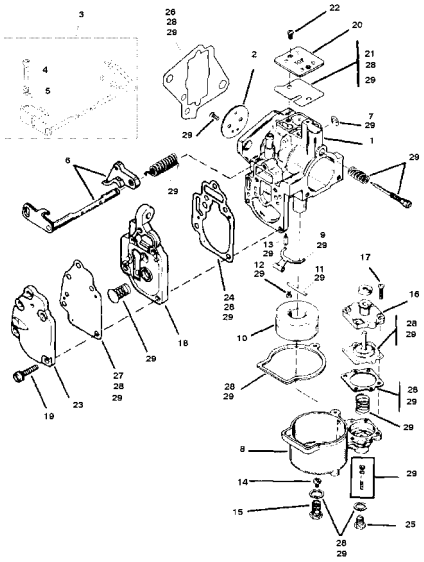

Figure 15 Carburettor assembly

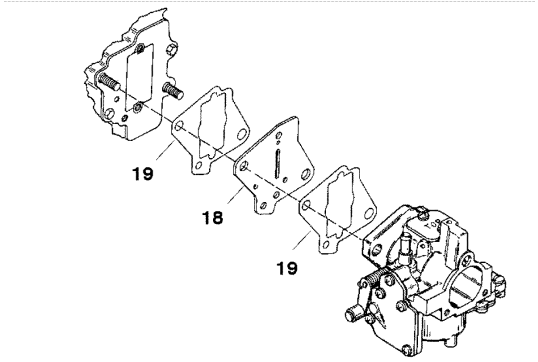

Figure 16 Carburettor and reed assembly

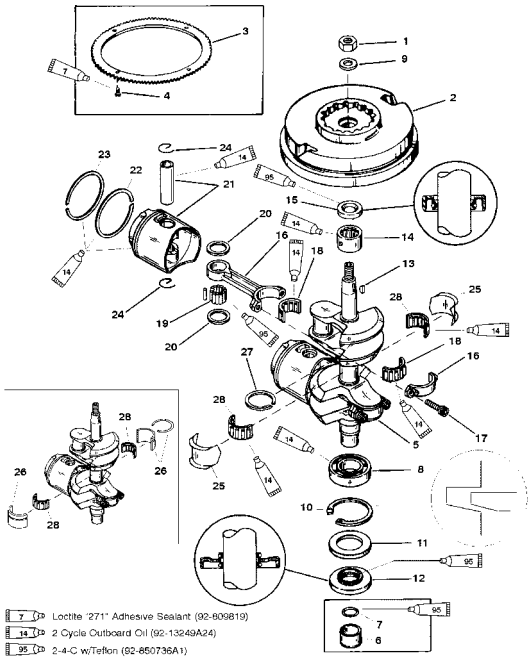

Figure 17 Crankshaft assembly

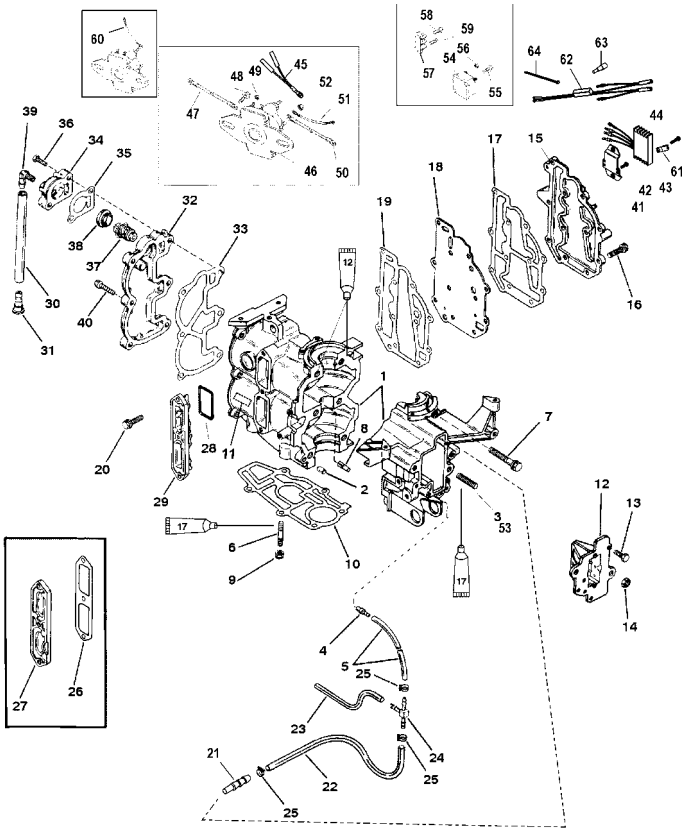

Figure 18 Cylinder block assembly

13 Appendix G

Design FMEA table for Stihl FS45 Line-trimmer

POTENTIAL FAILURE MODE AND EFFECT ANALYSIS DESIGN FMEA FOR STIHL BRUSHCUTTER FS45									
							Prepared by JRM		
Date: 10/10/2002							Core Team: JRM, PTG, LAG		
Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Plastic Fuel Tank	**contains fuel**	**fuel leak**	**fuel leak**	**9**	**hole in tank - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	prevents contamination of fuel	fuel contaminated	engine lacks power rough engine operation	6	hole in tank - material degradation	10	Material Compatibility Tests, Engine Testing	1	60
Fuel Tank cap	seals tank	leaks fuel contamination	engine lacks power rough engine operation	6	cap distorted, hole in cap - material degradation	10	Material Compatibility Tests, Engine Testing	1	60
	displays fuel level	shows incorrect level	engine stops	2	mechanism jammed, float sinks - material degradation	10	Material Compatibility Tests, Engine Testing	1	20
	vents tank	blockage vapour release	engine stops excessive evaporative emissions	5	vent blocked or distorted - material degradation	10	Material Compatibility Tests, Engine Testing	1	50
	allows tank to be filled	**cap cannot be removed**	**tank cannot be filled - engine stops**	**8**	**cap distorted, stuck to tank - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**80**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Filler cap attachment assembly	**attaches fuel filler cap to fuel tank**	**filler cap not attached to fuel tank**	**Debri blocks fuel filter - lack of power Fuel cap loss**	**1**	**fuel attacks material - material degradation**	**10**	**Test material compatibility Test running engine**	**1**	**10**
Fuel Pickup Screen	prevents debris entering fuel line	debris passes filter	blockage of fuel lines and primer bulb mechanism - engine stops	5	screen material attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	50
	transfer fuel	**blockage**	**engine stops lack of power**	**8**	**screen material attacked by fuel - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**80**
Fuel Pickup Tube	**transfer of fuel**	**blockage air leak fuel leak**	**engine stops lack of power**	**9**	**tube attacked by fuel, blocking flow - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	seals fuel (against fuel tank)	fuel leak	fuel leak	9	tube attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	90
	holds pickup screen	screen falls off tube	blockage of fuel lines - engine stops	6	tube attacked by fuel - material degradation	10	Material Compatibility Tests, Engine Testing	1	60
Air cleaner	**removes particles from inlet air**	**Particles travel through filter assembly**	**Dust and contaminates enter engine - engine seizure**	**8**	**fuel attacks air cleaner - material degradation**	**10**	**Test material compatibility Test running engine**	**1**	**80**
	transfers air	blockage	blockage - rough engine operation lack of power	8	fuel attacks air cleaner - material degradation	10	Test material compatibility Test running engine	1	80

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Air cleaner housing	**retains air cleaner**	**Fails to retain air filter**	**Dust and contaminates enter engine, engine seizure**	**8**	**fuel attacks material - material degradation**	**10**	**Test material compatibility Test running engine**	**1**	**80**
Choke lever	**richen air fuel mixture**	**lever cannot move**	**Engine will eventually start**	**6**	**fuel attacks material - material degradation**	**10**	**Test material compatibility Test running engine**	**1**	**60**
Air cleaner housing gasket	**seal air**	**seal not maintained**	**Air cleaner assembly not secured correctly dust and contaminates enter engine - engine seizure**	**8**	**fuel attacks material - material degradation**	**5**	**Test material compatibility Test running engine**	**1**	**40**
Primer bulb	pump element to prime fuel system	fails to pump fuel	engine will eventually start	6	bulb is attacked by fuel, become to hard to squeeze or hole is formed and bulb cannot hold pressure - material degradation	10	Material Compatibility Tests, Engine Testing	1	60
	transfer of fuel	**blockage air leak fuel leak**	**engine stops lack of power fuel leak**	**9**	**bulb is attacked by fuel, hole is formed and bulb cannot hold pressure, bulb distorts blocking flow path - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Primer housing	housing for primer bulb valve arrangement	fails to house components	primer pump will not function - engine will eventually start	6	material is attacked by fuel, distorts - material degradation	10	Test material compatibility Test running engine	1	60
	transfer of fuel	**blockage** **fuel leak**	**engine stops**	**9**	**material is attacked by fuel, distorts and block fuel flow - material degradation** **gumming**	**10**	**Test material compatibility** **Test running engine**	**1**	**90**
Primer housing gasket	**seals fuel**	**seal not maintained**	**fuel leak**	**9**	**fuel attacks material - material degradation**	**5**	**Test material compatibility** **Test running engine**	**1**	**45**
Carburettor body	housing for components	components not located correctly	fuel metering affected - rough engine operation lack of power	6	corrosion of materials retaining components - material degradation	10	Material Compatibility Tests, Engine Testing	1	60
	transfer of fuel	**blockage** **fuel leak**	**engine stops** **lack of power** **fuel leak**	**9**	**fuel attacks material, corrosion blocks flow path - material degradation** **gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
	transfer of air	air flow blocked	lack of power	6	air flow blocked by corrosion or deposits - material degradation fuel properties	2	Material Compatibility Tests, Engine Testing	1	12
	mixing of fuel and air	air and fuel not mixed	rough engine operation lack of power	6	air or fuel flow blocked or altered, fuel does not atomise or vaporise - material degradation gumming fuel properties	10	Material Compatibility Tests, Engine Testing	1	60
Throttle blade	**controls airflow**	**incorrect airflow control**	**lack of power**	**6**	**throttle blade corrodes, sticks to carb body - material degradation**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**12**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Throttle shaft	actuator for throttle blade	throttle blade cannot be actuated	lack of power Throttle sticks WOT	10	throttle shaft corrodes, sticks to carb body - material degradation gumming	4	Material Compatibility Tests, Engine Testing	1	40
	seal against carburettor body	**air leak into carburettor**	**rough engine operation lack of power**	**6**	**throttle shaft or carb body corrode - material degradation**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Throttle blade screw	**secures throttle blade to throttle shaft**	**throttle blade not secured**	**throttle sticks during operation**	**10**	**screw corrodes to failure - material degradation**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**20**
Regulator diaphragm	actuates needle valve	fails to actuate needle valve	rough engine operation lack of power engine stops fuel leak	9	fuel attacks material - material degradation gumming	10	Test material compatibility Test running engine	1	90
	seals fuel	**fails to seal fuel**	**fuel leak**	**9**	**fuel attacks material - material degradation**	**10**	**Test material compatibility Test running engine**	**1**	**90**
Needle valve	**controls fuel flow**	**fuel flow not controlled**	**float level incorrect - rough engine operation lack of power fuel leak**	**9**	**needle and seat corrode - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Needle control arm	**actuates needle valve**	**needle valve not actuated**	**fuel level incorrect - rough engine operation lack of power fuel leak**	**9**	**lever corrodes sticks - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Control arm pivot	**pivots float lever**	**float cannot move**	**fuel level incorrect - rough engine operation lack of power fuel leak**	**9**	**pin corrodes and lever sticks - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**
Pivot retaining screw	**retains float pin**	**float pin not retained**	**float lever cannot move correctly - rough engine operation fuel leak lack of power**	**9**	**screw corrodes to failure - material degradation**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**18**
Main fuel nozzle	**mixes fuel and air**	**fuel and air do not mix correctly**	**rough engine operation lack of power**	**6**	**air or fuel flow blocked or altered, fuel does not atomise or vapourise - material degradation fuel properties gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Low speed mixture screw	**mixture adjustment**	**fuel air mixture cannot be adjusted**	**rough engine operation**	**6**	**mixture screw corrodes altering mixture strength - material degradation gumming - deposits from fuel**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Low speed mixture screw O-ring	**seals air and fuel**	**fuel leak air leak**	**rough engine operation**	**6**	**elastomer attacked by fuel - material properties**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
High speed mixture screw	**mixture adjustment**	**fuel air mixture cannot be adjusted**	**rough engine operation lack of power**	**6**	**mixture screw corrodes altering mixture strength - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
High speed mixture screw O-ring	**seals air and fuel**	**fuel leak air leak**	**rough engine operation**	**6**	**elastomer attacked by fuel - material properties**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Main fuel jet	**metering fuel**	**fuel not metered correctly**	**rough engine operation lack of power**	**6**	**fuel jet corrodes altering metering - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**60**
Elbow fittings	retain fuel lines	fuel line detach	fuel leaks engine stops	9	fuel attacks material, corrosion blocks flow path - material degradation	10	Test material compatibility Test running engine	1	90
	transfer of fuel	**blockage fuel leak**	**engine stops lack of power fuel leak**	**9**	**fuel attacks material - material degradation gumming**	**10**	**Material Compatibility Tests, Engine Testing**	**1**	**90**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Cover	**supports diaphragm edges**	**diaphragm not supported**	**fuel leak**	**9**	**supports gasket, if gasket seal fuel, fuel has no effect on cover**	**2**	**Material Compatibility Tests, Engine Testing**	**1**	**18**
Cover screw	**secures pump cover**	**cover not secured**	**Fuel leak Engine stops**	**9**	**component corrodes to failure - material degradation**	**2**	**Test material compatibility Test running engine**	**1**	**18**
Pump diaphragm and check valves	**pumps fuel**	**fails to pump fuel fuel leak to crankcase**	**Engine stops fuel leak**	**9**	**fuel attacks diaphragm - material degradation**	**10**	**Test material compatibility Test running engine**	**1**	**90**
	directs fuel flow	fails to direct fuel flow	Engine stops	8	fuel attacks check valve - material degradation gumming	10	Test material compatibility Test running engine	1	80
Cover gasket	**seals fuel**	**does not seal**	**fuel leak**	**9**	**fuel attacks material - material degradation**	**5**	**Material Compatibility Tests, Engine Testing**	**1**	**45**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Inlet insulating block	**transfers air fuel mix**	**fail to transfer fuel air mix**	**Fuel leak Lack of power**	**9**	**fuel attacks material - material degradation**	**10**	**Test material compatibility Test running engine**	**1**	**90**
	insulates carburettor from heat	fails to insulate	engine will not start	6	fuel attacks material - material degradation	10	Test material compatibility Test running engine	1	60
Inlet heat shield/Gasket	**seal fuel air mix**	**fails to seal**	**Fuel leak Lack of power**	**9**	**fuel attacks material - material degradation**	**5**	**Test material compatibility Test running engine**	**1**	**45**
	shields carburettor from heat	fails to shield carburettor	engine will not start	6	fuel attacks material - material degradation	5	Test material compatibility Test running engine	1	30
Piston	compress air fuel mixture	fails to compress mixture	engine will not start lack of power rough engine operation engine seizure	8	hole in piston - altered combustion	10	Engine Testing	3	240
	controls opening and closing of ports	fails to control opening and closing of ports	no airflow through engine, engine will not start	8	erosion of piston crown will alter port timing - altered combustion	2	Engine Testing	3	48
	provides a bearing surface	**fails to provide a bearing surface**	**engine seizure**	**8**	**corrosion of bearing surfaces - material degradation lubrication deficiency**	**10**	**Engine Testing**	**3**	**240**
	transmit gas pressure loads to the connecting rod	fails to transmit gas loads to the connecting rod	lack of power engine seizure	8	hole in piston, piston seizure, high friction - altered combustion lubricant deficiency	10	Engine Testing	3	240

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Piston Rings	seals between cylinder volume and crankcase	fails to seal	lack of power engine will not start	6	ring wear, ring jacking, ring stick - altered combustion lubricant deficiency	10	Engine Testing	3	180
	transfers heat	**fails to transfer heat**	**lack of power knock piston overheats - engine seizure**	**8**	**ring wear, ring jacking, ring stick - altered combustion lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**
Piston Pin Clip	**retains piston pin**	**fails to retain piston pin**	**engine seizure**	**8**	**corrosion of pin clip to failure - material degradation**	**2**	**Engine Testing**	**3**	**48**
Piston Pin	connects connecting rod and piston	fails to connect connecting rod and piston	engine seizure	8	corrosion of pin - material degradation	2	Engine Testing	3	48
	provides bearing surface	**fails to provide a bearing surface**	**engine seizure**	**8**	**corrosion of pin - material degradation lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**
Bearings	transmit load between bearing surfaces	fails to transmit load between bearing surfaces	lack of power	6	corrosion of bearing surfaces, increased friction - material degradation lubricant deficiency	10	Engine Testing	3	180
	allow relative movement between surfaces	**fails to allow relative movement**	**lack of power engine seizure**	**8**	**corrosion of bearing surfaces, increased friction - material degradation lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Crankshaft	**provides bearing surfaces**	**fails to proide suitable bearing surface**	**lack of power engine seizure**	**8**	**corrosion of bearing surfaces, increased friction - material degradation lubricant deficiency**	**10**	**Engine Testing**	3	**240**
	provides sealing surfaces	fails to provide sealing surface	lack of power rough engine operation	6	corrosion of seal surface on crank - material degradation	10	Engine Testing	3	180
	locates major components	fails to locate major components	engine seizure	9	Corrosion of crank to failure - material degradation	10	Engine Testing	3	270
	converts connecting rod loads to torque	fails to convert connecting rod load to torque	lack of power	6	Corrosion of crank to failure - material degradation	10	Engine Testing	3	180
Crank seals	**seals fuel air mixture**	**fails to seal**	**fuel leak lack of power rough engine operation**	**9**	**fuel attacks seal - material degradation lubricant deficiency**	**10**	**Engine Testing**	**1**	**90**
Connecting rod	**provides bearing surfaces**	**fails to proide suitable bearing surface**	**lack of power engine seizure**	**8**	**corrosion of bearing surfaces, increased friction - material degradation lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**
	transmit piston loads to crankshaft	fails to transmit pistons loads to crankshaft	lack of power	6	Corrosion of rod to failure - material degradation	2	Engine Testing	3	36
Spark-plug	**ignites fresh charge**	**fails to ignite fresh charge**	**rough engine operation lack of power engine will not start**	**6**	**foulling, incorrect heat range electrodes damaged through knock or preignition - altered combustion**	**10**	**Engine Testing**	**3**	**180**
Barrel gasket	**seals fuel air mixture**	**fails to seal**	**fuel leak lack of power rough engine operation**	**9**	**fuel attacks seal - material degradation**	**5**	**Engine Testing**	**3**	**135**

Item	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	Occurrence	Current Design Controls	Detection	RPN
Barrel	housing for engine components	fails to house engine components	engine seizure	8	corrosion of materials reatining components - material degradation	2	Engine Testing	3	48
	provides bearing surface	**fails to provide bearing surface**	**engine seizure lack of power**	**8**	**excessive piston and bore temperatures or water in fuel causing loss of lubrication - altered combustion lubricant deficiency**	**10**	**Engine Testing**	**3**	**240**
	transfers fresh charge	fails to transfer fresh charge	rough engine operation lack of power	6	transfer port is blocked by deposits from exhaust gas - fuel properties	1	Engine Testing	3	18
	transfers exhaust gas	fails to transfer fresh charge	rough engine operation lack of power	6	exhaust port is blocked by deposits from exhaust gas - fuel properties altered combustion lubricant deficiency	1	Engine Testing	3	18
	contains fresh charge	fails to contain fresh charge	fuel leak lack of power rough engine operation	9	cylinder block corrodes and a hole is formed in crankcase - material degradation	6	Engine Testing	3	162
Crankcase	housing for engine components	fails to house engine components	engine seizure	8	corrosion of materials reatining components - material degradation	2	Engine Testing	3	48
	provides bearing surface	**fails to provide bearing surface**	**engine seizure**	**8**	**corrosion of materials reatining components - material degradation**	**10**	**Engine Testing**	**3**	**240**
	contains fresh charge	fails to contain fresh charge	fuel leak lack of power rough engine operation	9	corrodes and a hole is formed in crankcase - material degradation	6	Engine Testing	3	162