Baseline and monitoring methodology for the reduction of jet engine emissions through the use of engine washing technology

A methodology proposed for the
Voluntary Carbon Standard
Version 1.1

September 10, 2009

This methodology was developed by Det Norske Veritas Certification, Inc. in collaboration with United Technologies Corporation and Pratt & Whitney.

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1 METHODOLOGY TITLE AND VERSION

"Reduction of Jet Engine Emissions Through the Use of Engine Washing Technology"
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2 SUMMARY

This methodology was developed to calculate the quantity of emission reductions generated by washing jet engines. All engines become contaminated through normal operation leading to restricted airflow, higher exhaust gas temperature, and increased fuel consumption. By eliminating engine contamination, engine washings improve propulsive efficiency measured as a decrease in thrust specific fuel consumption or TSFC, resulting in decreased emissions of carbon dioxide (CO_2).

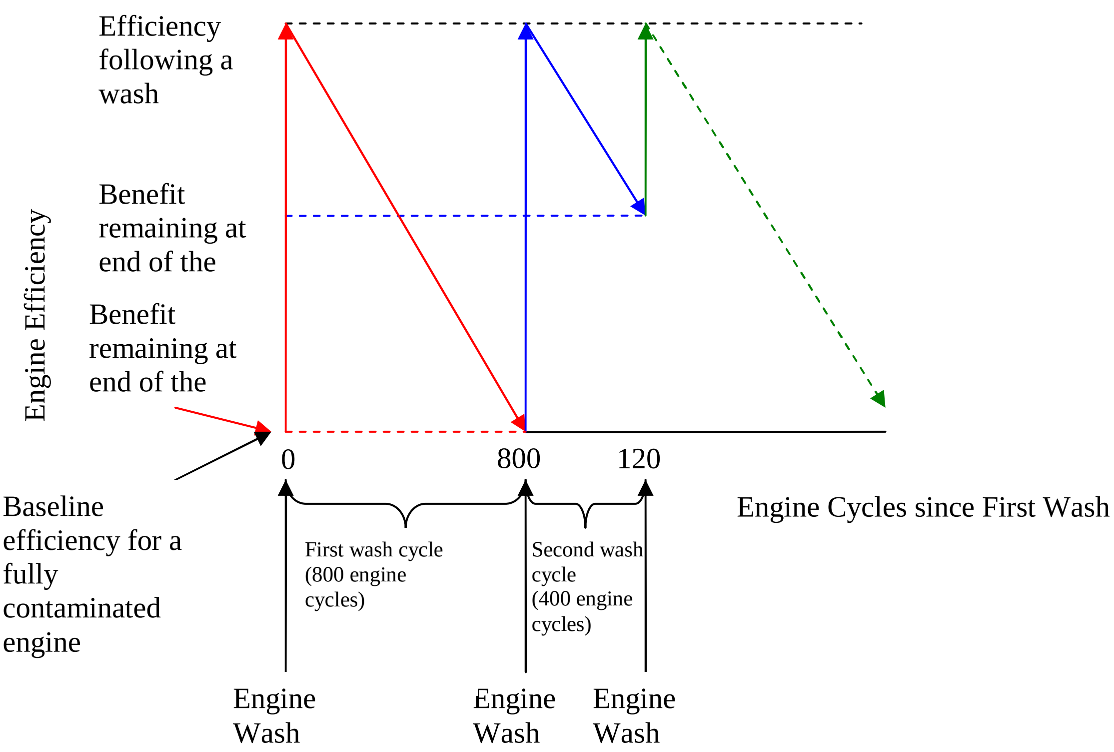
Figure 1 illustrates the general process of washing a jet engine. Once an engine is washed, it starts a wash cycle defined as the interval between two consecutive washes. As a result of the washing, engines will experience improved propulsive efficiency while in operation; the operation of an engine between one takeoff and one subsequent landing is called an engine cycle. As the number of engine cycles increase, the engine will become re-contaminated and the efficiency improvement realized by the washing will decline until the engine is washed again. The change in the efficiency improvement during the first washing cycle is tracked in red in Figure 1. This second washing terminates the first cycle and begins the subsequent cycle. The change in efficiency during the second wash cycle is tracked in blue in Figure 1. As demonstrated in Figure 1, washing cycles may not contain the same number of engine cycles for a variety of reasons, including:

- Safety procedures – Some maintenance procedures prevent all engines on an aircraft from being washed at the same time. This reduces the risk that the same mistake made on one engine will be repeated on all engines of an aircraft, thus reducing the chance that all engines will fail at the same time.

- Scheduling – Due to time constraints, it may not be feasible to wash all engines on an aircraft at once. Also, as engines are routinely switched between airplanes, the optimal wash interval for one engine may be different from that of the other engine on the same plane.

Since the number of engine cycles is directly correlated to the change in efficiency following a washing, the average efficiency improvement realized during the washing cycle will differ. Taking into account the average efficiency benefit realized during the wash cycle and the amount of fuel consumed by each engine cycle in a wash cycle, the fuel savings can be calculated and converted to emission reductions.

Figure 1 – Illustration of Engine Washing Process



3 SOURCE, DEFINITIONS AND APPLICABILITY

3.1 Source

The approach for this baseline and monitoring methodology is based on elements from AMS II.J., the approved small-scale baseline and monitoring methodology for demand-side activities for efficient lighting technologies. Jet engine washing technology is similar to lighting technology under AMS II.J. in that both technologies provide benefits that may increase their market penetration in the baseline scenario. However, the market penetration of both technologies will increase far more rapidly under the project case. In the two methodologies, it is the additional market penetration growth achieved due to the project activities that are counted as emission reductions.

For more information regarding the methodology, please refer to http://cdm.unfccc.int/goto/MPappmeth.

3.2 Defintions

For the purpose of this methodology, the following definitions apply:

- **Engine cycle** The operation of an engine between one takeoff and one subsequent landing
- **Fleet** refers to a group of identical engines that use the same type of jet fuel and are attached to the same type of aircraft frame
- **Cruise EGT** refers to exhaust gas temperature (degrees Celsius) recorded during flight
- **Cruise Fuel Flow** refers to the rate (lbs per hour) at which fuel is consumed by the engines during flight
- **Exhaust Gas Temp (EGT)** refers to temperature of the engine exhaust gases resulting from combustion of the fuel mixture, expressed in degree Celsius
- **Participant** refers to an individual airline that has agreed to wash all or a part of their fleet
- **Program Organizer** refers to the entity that is organizing airlines to wash all or part of their fleet
- **Project's engine washing technology** refers to any engine washing technology that decreases TSFC through the removal of engine contamination
- **Take off EGT** refers to engine exhaust gas temperature (degrees Celsius) recorded during takeoff
- **Thrust Specific Fuel Consumption (TSFC)** is an engineering term referring to fuel efficiency of an engine. TSFC represents the amount of fuel an engine burns to produce thrust.
- **Wash** refers to the cleaning of an individual jet engine
- **Washing cycle** refers to the interval between consecutive washes for a particular engine

3.3 Applicability Conditions

This methodology applies to programs that promote jet engine washing practices by providing incentives such as reduced cost of washings. Providing incentives that are funded by carbon credit sales enables airlines that would not have washed their aircraft engines in a baseline scenario to participate in the program.

The methodology is applicable under the following conditions:

- The project engine washing technology cleans any or all three of the compressive components of an engine: fan, low pressure compressor, and high pressure compressor. Project engine washing results in reduced fuel consumption through increased propulsive efficiency.
- The only emission reductions claimed under this methodology are those related to increased propulsive efficiency due to engine washing. The project will not claim any emissions reductions as a result of other measures that result in changes in fuel consumption, e.g., changes

in routes, operators' behaviour, etc, or fuel chemical property changes which increase fuel combustion efficiency.

- The engine is left on-wing during the washing and the engine washing technology is transported to the engine as opposed to removing the engine from the wing and transporting it to another location for the engine wash.

- The project technology uses a closed-loop system. All materials are collected and processed. All discharges meet appropriate environmental standards.

- The decline in the TSFC improvement due to engine recontamination following an engine washing occurs in a linear fashion.

- Realizing that the project engine washing technology is not currently common practice but provides economic benefits in the form of fuel savings that may increase its future market penetration, the crediting period is limited to five years.

4 BASELINE METHODOLOGY PROCEDURE

4.1 Project Boundary

The project boundary is the physical, geographical location of each engine washed by the project technology including all flight routes.

The greenhouse gases included in or excluded from the project boundary are shown in Table 1.

Table 1: Emissions sources included in or excluded from the project boundary

Source		Gas	Included?	Justification / Explanation
Baseline	Jet engines that are washed in the project case	CO_2	Yes	Emissions from fuel combustion represent the major emission source in the baseline
		CH_4	No	Negligible
		N_2O	No	Negligible
Project activity	Jet engines that are washed by the project technology	CO_2	Yes	Emissions from fuel combustion represent the major emission source in the project case
		CH_4	No	Negligible
		N_2O	No	Negligible
	Energy use during engine wash	CO_2	Yes	Maybe an important emission source
		CH_4	No	Negligible
		N_2O	No	Negligible
	Vehicles that transport engine wash equipment	CO_2	Yes	Maybe an important emission source
		CH_4	No	Negligible
		N_2O	No	Negligible

4.2 Identification of the baseline scenario

The project baseline is the existing level of propulsive efficiency or the amount of fuel that would be used by jet engines without the project activity.

4.3 Procedure for demonstrating additionality

Additionality shall be demonstrated using the latest version of the "*Tool for the demonstration and assessment of additionality*" that is available on the UNFCCC website. The "*Tool for the demonstration and assessment of additionality*" should be applied from the perspective of the program organizer undertaking the project activity.

4.4 Baseline emissions

The following equations are used to estimate the baseline emissions for jet engines:

$$BE_y = \sum_{m}^{z} \left(BFC_y * EF_{CO2,ACFuel,y} \right) \qquad \textbf{(1)}$$

Where:
BE_y = Baseline emissions in year *y* (t CO_2/yr)
m = An individual fleet
z = Total number of fleets
BFC_y = Baseline fuel consumption by all engines in fleet m in year y (mass or volume unit)
$EF_{CO2,ACFuel,y}$ = CO_2 emission factor for fuel used in fleet *m* engines (ton CO_2/mass or volume unit)

Procedure for estimating the CO_2 emission factor for fuel used in jet engines, $EF_{CO2,ACFuel,y}$

$$EF_{CO2,ACFuel,y} = EF_{C,ACFuel,y} * 44/12 * OXID_{ACFuel} * NCV_{ACFuel} \qquad \textbf{(1.1)}$$

Where:
$EF_{CO2,ACFuel,y}$ = CO_2 emission factor for fuel used in aircraft engines in fleet *m* (metric ton of CO_2/mass or volume unit)
$EF_{C,ACFuel,y}$ = Carbon content of fuel used in aircraft engines in fleet *m* (metric ton/Tera Joule)
$OXID_{ACFuel}$ = Oxidation factor of fuel used in aircraft engines in fleet *m*
NCV_{ACFuel} = Net caloric value of fuel used in aircraft engines in fleet *m* (Tera Joule/mass or volume units)

Procedure for estimating the baseline fuel consumption, BFC_y

$$BFC_y = \sum_{j=1}^{n}\left[\sum_{wc=1}^{x}\left[\sum_{ec=1}^{NECj,wc} MFC_r\right]\right] \tag{1.2}$$

Where:

BFC_y = Baseline fuel consumption by all engines in fleet *m* in year *y* (mass or volume units)
j = An individual engine in fleet *m*
n = Total number of engines in fleet *m* in year *y*
wc = A wash cycle, or the interval between two consecutive washes
x = Total number of wash cycles for engine *j* in year *y*
$NEC_{j,wc}$ = Number of engine cycles for engine *j* during wash cycle, *wc*, not to exceed $ACFC_m$
ec = An engine cycle
MFC_r = Modelled fuel consumption in the baseline case, based on engine utilization (*r*) during the engine cycle (mass or volume units)

Note: If the fuel used in an engine is changed during the project crediting period, the engine will be assigned to a different fleet corresponding to the appropriate combination of aircraft frame, engine type and fuel type for the wash cycle when the fuel switch occurs and all subsequent wash cycles where the new fuel is used.

4.5 Project emissions

The following equation estimates the project emissions:

$$PE_y = \sum_{m}^{z}\left(PE_{EA,y} + PE_{WE,y}\right) \tag{2}$$

Where:

PE_y = Project emissions in year *y* (t CO_2)
m = An individual fleet
z = Total number of fleets
$PE_{EA,y}$ = Emissions from fuel combustion by fleet *m* in year y (t CO_2)
$PE_{WE,y}$ = Emissions generated in the process of washing fleet *m* engines in year y (t CO_2)

Procedure for estimating the project emissions associated with fuel combustion by fleet *m* engines in year *y*, $PE_{EA,y}$

$$PE_{EA,y} = FC_{.y} * EF_{CO2,ACFuel,y} \tag{2.1}$$

Where:

$PE_{EA,y}$ = Emissions from jet engine fuel combustion in year *y* (metric ton of CO_2)
FC_y = Fuel consumption by fleet *m* in year *y* (mass or volume unit)
$EF_{CO2,ACFuel,m,y}$ = Carbon dioxide emission factor of fuel used in fleet *m* engines (metric ton of CO_2/ mass or volume unit)

Procedure for estimating the CO_2 emission factor for the fuel used in engines in year *y*, $EF_{CO2,ACFuel,y}$

$$EF_{CO2,ACFuel,y} = EF_{C,ACFuel,y} * 44/12 * OXID_{ACFuel} * NCV_{ACFuel} \tag{2.1.1}$$

Where:

$EF_{CO2,ACFuel,y}$ = Carbon dioxide emission factor of fuel used in fleet *m* engines (metric ton of CO_2/ mass or volume unit)
$EF_{C,ACFuel,y}$ = Carbon content of fuel used in aircraft engines (metric ton/Tera Joule)
$OXID_{ACFuel}$ = Oxidation factor of fuel used in aircraft engines
NCV_{ACFuel} = Net caloric value of fuel used in aircraft engines (Tera Joule/mass or volume units)

Procedure for estimating the fuel consumption by fleet *m* in year *y*, $FC_{m,y}$

$$FC_y = \sum_{j=1}^{n}\left[\sum_{wc=1}^{x}\left[\left(\sum_{ec=1}^{NECj,wc} MFC_r\right) * \left(1 - \overline{TSFC_{j,wc}}\right)\right]\right] \tag{2.1.2}$$

Where:

FC_y = Fuel consumption by all engines in fleet *m* in year *y* (mass or volume units)
j = An individual engine in fleet *m*
n = Total number of engines in fleet *m* in year *y*
wc = A wash cycle, or the interval between two consecutive washes
x = Total number of wash cycles for engine *j* in year *y*
$NEC_{j,wc}$ = Number of engine cycles for engine *j* during wash cycle, *wc*, not to exceed $ACFC_m$
ec = An engine cycle
MFC_r = Modelled fuel consumption in the baseline case, based on engine utilization (*r*) during the engine cycle (mass or volume units)
$\overline{TSFC_{j,wc}}$ = Average TSFC improvement for engine *j* throughout the wash cycle, *wc*, due to wash *w* (%)

As described above, the benefit of a wash will vary for each washing cycle depending on the number of engine cycles. However, airlines do not track fuel consumption at the level of detail that would be required to determine fuel consumption per wash cycle (fuel consumption is tracked at the fleet level, not by aircraft, engine or cycle). Since data limitations prevent accurate reporting of fuel consumption by wash cycle in the project case, the baseline fuel consumption for each engine cycle is determined using industry standard models (as described in section V) and aggregated for each washing cycle. Wash cycle fuel consumption is then adjusted based on the average TSFC benefit realized during the wash cycle, to determine the wash cycle fuel consumption in the project case. This is aggregated across all wash cycles to determine annual fuel consumption for an engine, and then engine fuel consumption is aggregated across the fleet.

Note 1: If the fuel used in an engine is changed during the project crediting period, the engine will be assigned to a different fleet (corresponding to the appropriate combination of aircraft frame, engine type and fuel type) for the wash cycle when the fuel switch occurs and all subsequent wash cycles where the new fuel is used.

Note 2: Fuel consumption associated with engine cycles that are in excess of $ACFC_m$ during a particular wash cycle will not be included in this calculation. This is described further under equation 2.1.2.1.2

Procedure for estimating the average TSFC improvement per wash cycle, $\overline{TSFC_{j,wc}}$

$$\overline{TSFC_{j,wc}} = \left(\frac{\Delta TSFC_{j,w} + \Delta TSFC_{j,NECj,wc}}{2} \right) \tag{2.1.2.1}$$

Where:

$\overline{TSFC_{j,wc}}$ = Average TSFC improvement for engine *j* throughout the washing cycle, *wc*, due to wash *w* (%)

$\Delta TSFC_{j,w}$ = TSFC improvement for engine *j* following wash *w* (%)

$\Delta TSFC_{j,\ NECj,wc}$ = TSFC improvement remaining for engine *j* after $NEC_{j,wc}$ cycles following a wash

w = An individual engine washing

Immediately following a wash, aircraft engines will realize the greatest increase in TSFC (represented by $\Delta TSFC_{j,w}$) and this declines in a linear fashion as the engine becomes more contaminated with each engine cycle (as shown in Figure 1 above) until the end of the wash cycle (the TSFC improvement remaining at the end of the wash cycle is represented by $\Delta TSFC_{j\ ,\ NECj,wc}$). Since this decline is linear, the net effect of the wash throughout the wash cycle can be expressed as the average TSFC benefit.

Procedure for estimating the TSFC improvement for engine *j* following wash *w*, $\Delta TSFC_{j,w}$

$$\Delta TSFC_{j,w} = \Delta TSFC_m * \left(\frac{NEC_j}{ACFC_m} \right) \tag{2.1.2.1.1}$$

Where:

$\Delta TSFC_{j,w}$ = TSFC improvement for engine *j* following wash *w* (%)

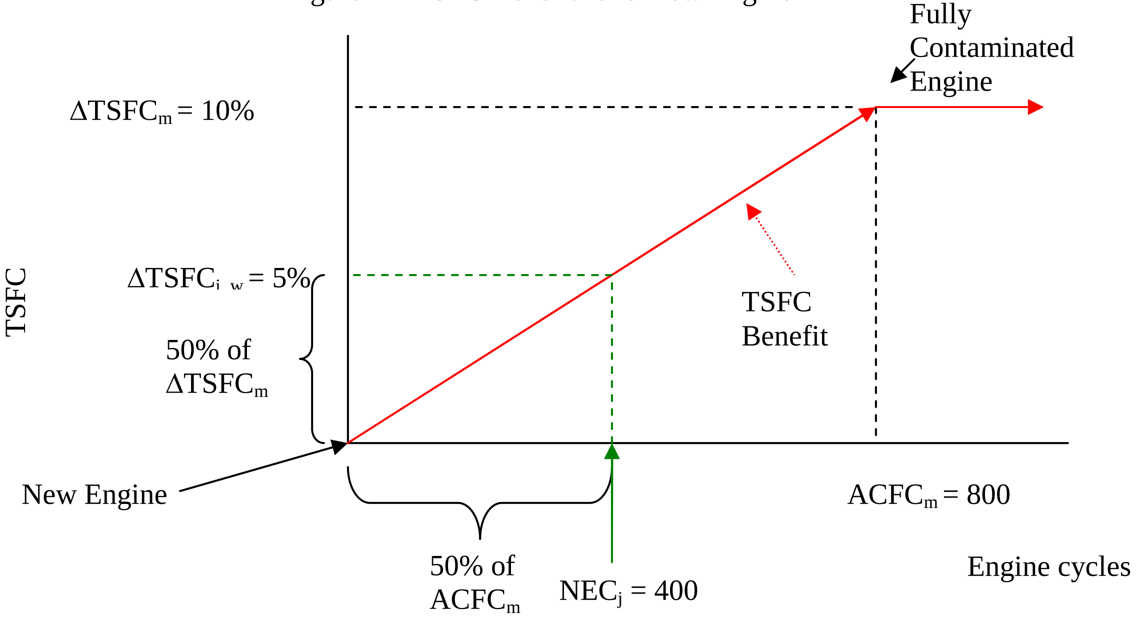
$\Delta TSFC_m$ = TSFC improvement for an engine in fleet *m* following a wash (%)

NEC_j = Number of engine cycles for engine j since it was put into service, not to exceed $ACFC_m$

$ACFC_m$ = Number of engine cycles that, in the absence of any engine washings, will lead a clean engine in fleet *m* to become fully contaminated.

Since jet engines are not washed in the baseline scenario, an engine that becomes fully contaminated would have remained so in the absence of the project. Therefore, the TSFC improvement following washing in the project case ($\Delta TSFC_{j,w}$) can, in most cases, be compared to a fully contaminated engine, as defined by $\Delta TSFC_{m.}$ The exception is an engine that has not yet travelled the number of cycles that causes full contamination as defined by $ACFC_m$, such as a new engine that has just been put into service. If an engine is washed before it reaches $ACFC_m$ cycles, it would be inappropriate to compare the wash benefit to the fully contaminated case. As engine contamination increases in a linear fashion relative to engine cycles until $ACFC_m$ is reached, and because engine contamination and TSFC benefit are directly correlated, the TSFC benefit for a wash that occurs before $ACFC_m$ cycles can be found by discounting the maximum TSFC benefit by the proportion of $ACFC_m$ cycles that has been reached before the wash takes place (see Figure 2).

Figure 2 – TSFC Benefit for a New Engine



Procedure for estimating the TSFC improvement remaining at the end of the wash cycle, $\Delta TSFC_{j,NECj,wc}$

$$\Delta TSFC_{j,NECj,wc} = \left(\Delta TSFC_m * \left(1 - \frac{NEC_{j,wc}}{ACFC_m} \right) \right)$$

(2.1.2.1.2)

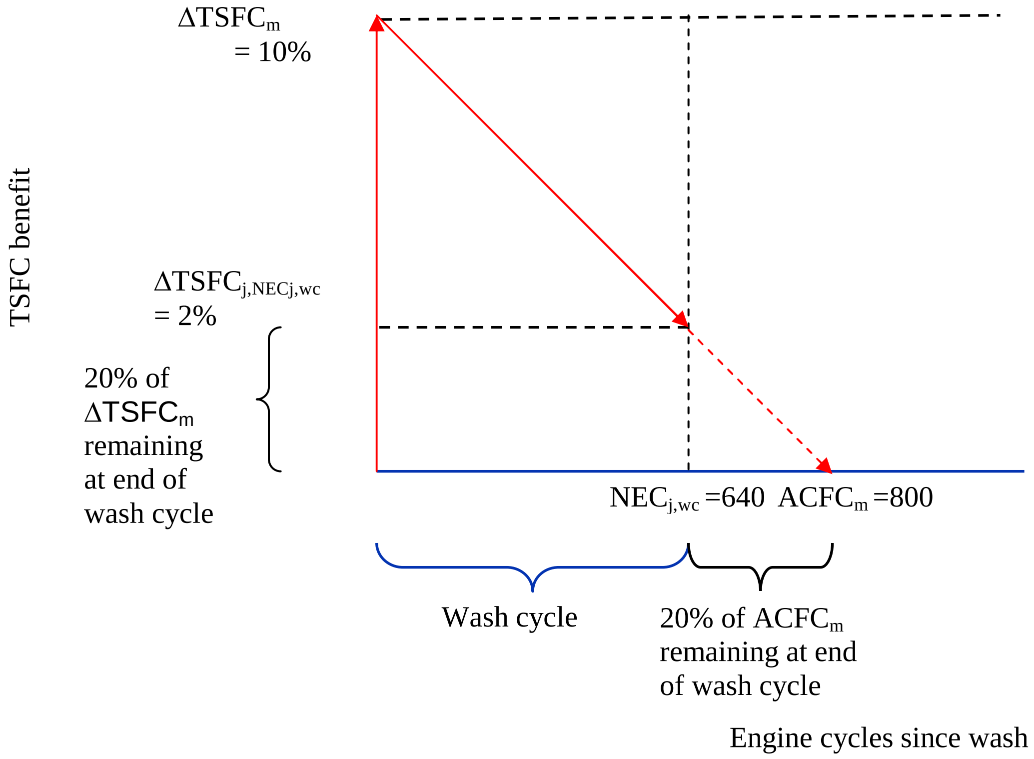
Where:

$\Delta TSFC_{j,NECj,wc}$ = TSFC improvement for engine *j* after $NEC_{j,wc}$ cycles following a wash
$\Delta TSFC_m$ = TSFC improvement for engine *j* following a wash (%)
$NEC_{j,wc}$ = Number of engine cycles for engine *j* during wash cycle, *wc*, not to exceed $ACFC_m$
$ACFC_m$ = Number of engine cycles that, in the absence of any engine washings, will lead a clean engine in fleet *m* to become fully contaminated.
w = An individual wash

If it were certain that the wash cycle would contain $ACFC_m$ engine cycles, equation 2.1.2.1 would simply take the average between $\Delta TSFC_{j,w}$ (the benefit immediately following wash *w*) and 0 (since $ACFC_m$ represents the point where the TSFC benefit is entirely lost). However, project participants may elect to shorten the wash cycle (note that cycles in excess of $ACFC_m$ are eliminated from consideration – see below), as demonstrated in figure 3. As a result, the TSFC benefit remaining at the end of this shortened wash cycle, $\Delta TSFC_{j, NECj,wc}$, is calculated in equation 2.1.2.1.2 Since the decline in TSFC is linear as the number of engine cycles increases, this equation calculates $\Delta TSFC_{j, NECj,wc}$ by multiplying the initial TSFC benefit by one minus the proportion of the maximum engine cycles realized during the wash cycle. For instance, if $ACFC_m$ is 800 and $NEC_{j,wc}$ is 8, then 1-(640/800) = 0.2. If the $\Delta TSFC_m$ is 10%, then the remaining TSFC benefit is 10% * 0.2 =2%.

As mentioned above, cycles in excess of $ACFC_m$ following a wash are eliminated from consideration. Once an engine reaches $ACFC_m$ cycles following a wash, it is by definition fully contaminated. The fuel efficiency is therefore no better than it would have been in the baseline and so the project does not provide any benefit that is greater than the baseline scenario.

Figure 3 – TSFC Benefit Remaining at End of Wash Cycle



Procedure for estimating the emissions generated during the engine washing process per year, $PE_{WE,y}$

$$PE_{WE,m,y} = GE_{m,y} + TE_{m,y} \tag{2.2}$$

Where:

$PE_{WE,y}$ = Emissions generated during the washing process in year *y* (t CO_2)
$GE_{m,,y}$ = Emissions from energy usage to run generators during the washing of engines in fleet *m* in year *y* (t CO_2)
$TE_{m,y}$ = Emissions from the transport of washing technology to the wash engines in fleet *m* in year *y* (t CO_2)

Procedure for estimating the emissions from energy usage to run the generator during the washing of engines in fleet *m*, *$GE_{m,y}$*

$$GE_{m,y} = \sum_{g}^{q} \left(FC_{gen,y} * EF_{CO2,GenFuel,y} \right) \tag{2.2.1}$$

Where:
$GE_{m,y}$ = Emissions from energy usage to run generators during the washing of engines in fleet *m* in year *y* (t CO_2)
g = A particular fuel used by generators during the washing of fleet *m* engines
q = Total number of different fuels used by all generators to wash engines in year *y*
$FC_{gen,y}$ = Fuel consumption by generators used to wash the engines of fleet m in year *y* (mass or volume of fuel)
$EF_{CO2,GenFuel,y}$ = CO_2 emission factor for the fuel consumed by generator *g* in year *y* (t CO_2/ mass or volume unit)

Procedure for estimating the fuel consumption by generators used to wash the engines of fleet *m* in year *y*, $FC_{gen,y}$

$$FC_{gen,y} = \sum_{j}^{n} \left[\sum_{w}^{x} \left(CR_{fuel} * D_w \right) \right] \tag{2.2.1.1}$$

Where:
$FC_{gen,y}$ = Fuel consumption by generators used to wash the engines of fleet *m* in year *y* (mass or volume of fuel)
j = An individual engine in fleet *m*
n = Total number of engines in fleet *m* in year *y*
w = An engine wash
x = Total number of engine washes for engine *j* in year *y* (note that the number of wash cycles is equal to the number of washes, and so the same variable *x* is used)
CR_{fuel} = Fuel consumption rate of the generator in year *y* (mass or volume of fuel per hour)
D_w = Length of time that the generator is in use during a wash (hours)

Procedure for estimating the CO_2 emission factor for the fuel consumed by the generator in year *y*, $EF_{CO2,GenFuel,y}$

$$EF_{CO2,GenFuel,y} = EF_{C,GenFuel,y} * 44/12 * OXID_{GenFuel} * NCV_{GenFuel} \tag{2.2.1.2}$$

Where:

$EF_{CO2,GenFuel,y}$ = CO_2 emission factor for the fuel consumed by the generator in year *y* (metric ton of CO_2/ mass or volume unit)
$EF_{C,GenFuel,y}$ = Carbon content of the fuel consumed by the generator (ton/Tera Joule)
$OXID_{GenFuel}$ = Oxidation factor of the fuel consumed by the generator (%)
$NCV_{GenFuel}$ = Net caloric value of the fuel consumed by the generator (Tera Joule/mass or volume units)

Procedure for estimating the emissions from the transport of washing technology to the wash location in year *y*, TE_y

$$TE_{m,y} = \sum_{f=1}^{l} \left(FC_{TV,fuel} * EF_{CO2,TVFuel,y} \right) \tag{2.2.2}$$

Where:

$TE_{m,y}$ = Emissions from the combustion of fuel in vehicles used to transport washing equipment to the wash location in year *y* (mass or volume unit)
f = A particular fuel used by vehicles to transport wash equipment to wash engines in fleet *m*
l = Total number of different fuels that are used by vehicles to transport wash equipment (i.e., propane and electricity)
FC_{TVF} = Fuel consumption by vehicles during the transport of washing equipment in year *y* (volume units)
$EF_{CO2,TVFuel,y}$ = CO2 emission factor for a fuel consumed by transport vehicles in year *y* (metric ton of CO_2/mass or volume unit)

Procedure for estimating the quantity of a particular fuel consumed in the transport of washing equipment, FC_{ETF}

$$FC_{TV,fuel} = \sum_{j=1}^{n} \left[\sum_{w=1}^{x} \left[\sum_{v=1}^{p} \left(TD / FE \right) \right] \right] \tag{2.2.2.1}$$

Where:

$FC_{TV,fuel}$ = Fuel consumption by vehicles during the transport of engine washing equipment in year *y* (volume units)
j = An individual engine in fleet m
n = Total number of engines in fleet m in year y
w = A wash
x = Total number of washings for engine *j*
v = A vehicle used to transport engine washing equipment for a wash
p = Total number of vehicles used to transport engine washing equipment for a wash
TD = Total distance travelled by a vehicle to transport washing equipment for a wash (distance units)
FE = Fuel efficiency of a vehicle used to transport washing equipment (volume units per distance units)

Procedure for estimating the CO_2 emission factor for fuel consumed by transport vehicles in year *y*, $EF_{CO2,TVF,y}$

$$EF_{CO2,TVFuel,y} = EF_{C,TVFuel,y} * 44/12 * OXID_{TVFuel} * NCV_{TVFuel} \qquad \textbf{(2.2.2.2)}$$

Where:

$EF_{CO2,TVFuel,y}$ = CO_2 emission factor for fuel consumed by transport vehicles in year *y* (metric ton of CO_2/mass or volume unit)
$EF_{C,TVFuel,y}$ = Carbon content of the fuel consumed by transport vehicles (metric ton/Tera Joule)
$OXID_{TVFuel}$ = Oxidation factor of the fuel consumed by transport vehicles (%)
NCV_{TVFuel} = Net caloric value of the fuel consumed by transport vehicles (Tera Joule/mass or volume units)

4.6 Leakage

There are no identified sources of leakage for this project activity

4.7 Emission reductions

Since the impact of an engine wash will vary by fleet, the calculation of emission reductions is done for each fleet and then aggregated across all fleets. Emission reductions are calculated as follows:

$$ER_y = \left(BE_y - PE_y\right) * BP \qquad \textbf{(3)}$$

Where:

ER_y = Emission reductions in year *y* (metric ton of CO_2e/yr)
BE_y = Baseline emissions in year *y* (metric ton of CO_2e/yr)
PE_y = Project emissions in year *y* (metric ton of CO_2/yr)
BP = Baseline penetration discount factor, a default value of 0.90 to be used unless a more appropriate value based on an aircraft engine washing survey from the same region and not older than 2 years is available. (see section IV “Emissions Reductions” for a discussion of the BP discount factor)

4.8 Changes required for methodology implementation in 2nd and 3rd crediting periods

This methodology is applicable for a five (5) year crediting period only, with no renewals.

5 MONITORING METHODOLOGY

All data collected as part of monitoring will be archived electronically and will be kept at least for 2 years after the end of the last crediting period. The data to be monitored is listed in the tables below. All measurements will be conducted with calibrated measurement equipment according to relevant industry standards.

In addition, the monitoring provisions in the tools referred to in this methodology apply.

5.1 Data and parameters not monitored

In addition to the parameters listed in the tables below, the provisions on data and parameters not monitored in the tools referred to in this methodology apply.

Data / parameter:	BP
Data unit:	%
Description:	Baseline penetration discount factor
Source of data:	Conservative assumption to eliminate non-additional washes.
Measurement procedures (if any):	
Any comment:	Default value =0.90

Data / parameter:	$ACFC_m$
Data unit:	Cycles
Description:	Number of engine cycles that, in the absence of any engine washings will lead a clean engine in fleet *m* to be fully contaminated.
Source of data:	Previous data analysis indicates that aircraft engines become fully contaminated between 800-1200 engine cycles, depending on the fleet and route. To assure the conservativeness of the emission reduction calculations, the default value has been set at 800 cycles.
Measurement procedures (if any):	
Any comment:	Default value = 800

5.2 Data and parameters monitored

Data / parameter:	r
Data unit:	Hours
Description:	Engine utilization for each cycle or hours of operation
Source of data:	Engine operator records
Measurement procedures (if any):	Record hours per cycle, as well as date and time of cycle and the engine serial number, so that utilization can be allocated to a particular engine and wash cycle
Monitoring frequency:	Continuously
QA/QC procedures:	
Any comment:	

Data / parameter:	w
Data unit:	Wash
Description:	A wash for engine j
Source of data:	Engine operator records
Measurement procedures (if any):	Record date and time of the aircraft engine wash as well as the engine serial number, so that fuel consumption can be assigned to a particular engine and wash cycle.
Monitoring frequency:	Continuously
QA/QC procedures:	
Any comment:	

Data / parameter:	ec
Data unit:	Engine Cycle
Description:	Engine cycle for engine *j*, where an engine cycle includes one takeoff and one landing.
Source of data:	Aircraft engine operator records
Measurement procedures (if any):	Record data and time of cycle, as well as engine serial number so that engine cycle can be assigned to a wash cycle
Monitoring frequency:	Continuously, aggregated per wash cycle. Cycles in excess of $ACFC_m$ are eliminated from consideration, as described in equation 2.1.2.1.2
QA/QC procedures:	
Any comment:	

Data / parameter:	g
Data unit:	Fuel type
Description:	Fuel type consumed by each generator that is used to wash engines in year *y*
Source of data:	Operator records
Measurement procedures (if any):	
Monitoring frequency:	Recorded one time per year
QA/QC procedures:	
Any comment:	

Data / parameter:	CR_{fuel}
Data unit:	Mass or volume of fuel per hour
Description:	Fuel consumption rate for each generator used to wash engines in year *y*
Source of data:	Vehicle manufacturers specification sheet
Measurement procedures (if any):	
Monitoring frequency:	Recorded one time per year
QA/QC procedures:	
Any comment:	

Data / parameter:	D_w
Data unit:	Hours
Description:	Length of time that a generator is in use during a wash
Source of data:	Measurements by project proponent
Measurement procedures (if any):	In addition to duration of generator use, record data and time of wash, as well as engine serial number(s). In lieu of continuously recording wash duration, average duration of 15 washes for engines with at least $ACFC_m$ cycles may be used as default value for all washes in the fleet. Fully contaminated engines can take longer to clean, resulting in a more conservative estimation of project emissions.
Monitoring frequency:	Continuously If default value is used, Recorded during first engine wash.
QA/QC procedures:	
Any comment:	The use of default values is acceptable because the emissions associated with energy use during the washing process are likely to be de-minimus.

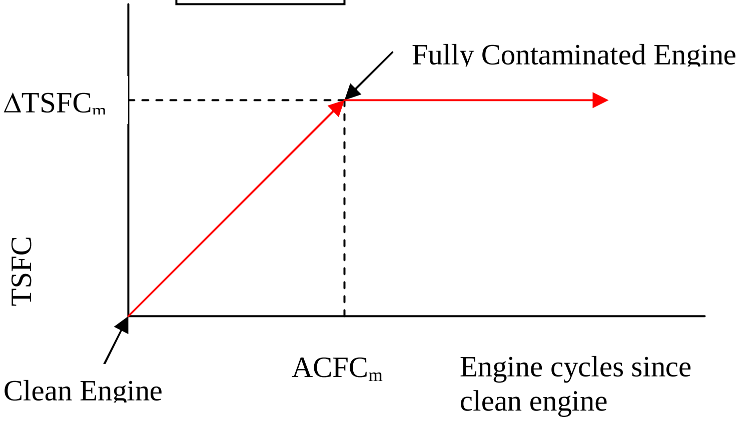
Data / parameter:	f
Data unit:	Fuel type
Description:	Fuel type consumed by a transport vehicle to transport wash equipment in year *y*
Source of data:	Vehicle operator records
Measurement procedures (if any):	
Monitoring frequency:	Continuously
QA/QC procedures:	
Any comment:	

Data / parameter:	TD_{TV}
Data unit:	Distance units
Description:	Total distance travelled by vehicles transporting engine washing equipment per engine wash
Source of data:	Vehicle odometer
Measurement procedures (if any):	Vehicle operator must record the roundtrip distance travelled for each engine wash, as well as the engine serial number that was washed and the time and date that the wash occurs. Alternatively, the vehicle operator can record the greatest roundtrip distance travelled to perform an engine wash for each location (i.e., airport), and this distance can be used as a default value for all other washings.
Monitoring frequency:	Roundtrip distance recorded for every washing. Alternatively, the distance is recorded once based on the greatest possible distance.
QA/QC procedures:	
Any comment:	

Data / parameter:	FE_{TV}
Data unit:	Mass or volume units per distance units
Description:	Fuel efficiency of a vehicle used to transport engine washing equipment to the wash location
Source of data:	Vehicle manufacturers specification sheet
Measurement procedures (if any):	
Monitoring frequency:	Recorded one time per year
QA/QC procedures:	
Any comment:	

Data / parameter:	$\Delta TSFC_m$
Data unit:	%
Description:	TSFC improvement for an engine in fleet *m* following a wash (%)
Source of data:	Engine trend data obtained from aircraft operator, including Takeoff EG Margin, Cruise EGT and Cruise Fuel Flow

Measurement procedures (if any):	To calculate $\Delta TSFC_m$, data must be collected for a period of time before and after the wash such that accurate levels can be obtained for each period of time. This data is then analyzed to determine the TSFC benefit of each wash. The TSFC benefit corresponding to the wash cycle length (which corresponds to the number of engine cycles in the wash cycle or the number of cycles required for the engine to become fully contaminated) and the wash cycle length can then be determined through interpretation of the individual wash TSFC benefits plotted vs. NEC on a scatter plot. The point at which the TSFC benefit plateaus is the benefit that can be expected by a wash of a fully contaminated engine, or $\Delta TSFC_m$. The number of engine cycles that corresponds to $\Delta TSFC_m$ is $ACFC_m$. This is shown in Figure 1. <u>Step 1</u> - To calculate the TSFC improvement for varying wash cycle lengths, the following procedure is used: For each of the following variables - Takeoff EGT Margin, Cruise EGT and Cruise Fuel Flow data – obtain 20 data points before the wash and 20 data points after the wash from engine trend data. These data points should be collected for the engine cycle immediately preceding and immediately following the wash for washed engines of the fleet in question. Make sure that all data acquired is normalized to account for differences in ambient conditions and power setting. Most industry-standard engine monitoring software programs provide fully normalized data that can be evaluated directly. If this is not available, raw data can be acquired and normalized manually. Detect and correct any biases that may be present in the data. Identify any trends in the data or performance shifts occurring before or after the wash that are not related to the wash. Omit data before the wash or after the wash that show the trend or performance shift. Omit outlier data that is greater than the appropriate variation threshold (typically 2 standard deviations) from the data population average. A minimum of 10 cruise data points (data points collected while aircraft are cruising during operation) before the wash and 10 cruise data points following the wash must remain following step 2 for accurate analysis. If fewer than 10 cruise data points are available, a new dataset must be collected. For each variable, calculate the difference between the average of the remaining points following the wash and the remaining points prior to the wash. This difference will be defined as the "delta_delta". Input the measured "delta_delta" parameters (including Cruise WF and Cruise EGT) into a thermodynamic engine model or use an applicable correlation coefficient to calculate the TSFC improvement for that wash. If correlations are used, compare the TSFC calculated based on WF and EGT to ensure accurate results. If the TSFC benefits calculated based on various parameters agree within an acceptable threshold, the data is considered valid and TSFC_WF will be considered the wash benefit for that wash ($\Delta TSFC_{m)}$. If the TSFC benefits as calculated based on Cruise WF and Cruise EGT do not agree within 0.30, a new dataset must be collected and analyzed.

	Step 2 – Once sufficient data points have been collected under Step 1 for the fleet (approximately 30), they are analyzed to determine $\Delta TSFC_{m.}$ This is accomplished through a linear regression of wash TSFC benefits vs. engine cycles, where the regression is forced through the origin. For the purposes of this regression, all washes taking place after more than $ACFC_m$ cycles will be re-defined as taking place at $ACFC_m$ cycles. The $\Delta TSFC_m$ benefit for each fleet will then be equivalent to the $ACFC_m$ contamination cycle intercept of the TSFC benefit regression line. Figure 1 
Monitoring frequency:	Analysis is conducted when data from a statistically significant number of engine washes has been collected from each fleet. At least 50% of each fleet must be analyzed. Analysis is performed once and the resulting $\Delta TSFC_m$ value is applicable for the entire crediting period.
QA/QC procedures:	
Any comment:	- Project proponents must demonstrate to the VCS board the applicability of the models used in Steps 2 and 5. - No performance shifting activities (i.e., as instrumentation changes, software upgrades, engine maintenance or upgrades) should be conducted between the measurement of pre and post-wash data.

Data / parameter:	MFC_r
Data unit:	Mass or volume units
Description:	Modelled fuel consumption in the baseline case, based on engine utilization (*r*) during the engine cycle
Source of data:	Data is modelled based on: utilization rates (average cycles per year and hours/cycle) as reported from aircraft operators, and fleet performance specifications obtained from airplane performance documents.
Measurement procedures (if any):	Aircraft operators report total engine cycles and total hours per year for the fleet. The average cycles per year and average hours per cycle for the fleet are calculated and these averages are used as inputs to the model.
Monitoring frequency:	Annual ex-post analysis
QA/QC procedures:	
Any comment:	Project proponents must demonstrate to the VCS board the applicability of the model used to estimate fuel consumption. Acceptable models include, inter alia, those used to certify aircraft engine performance specifications.

Data / parameter:	NCV_{ACFuel}
Data unit:	Mega Joule / mass or volume units
Description:	Net caloric value of fuel used in aircraft engines
Source of data:	Actual measured or local data are to be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$EF_{C,ACFuel,y}$
Data unit:	metric tons of carbon / mass or volume units
Description:	Carbon content of the fuel combusted in aircraft engines
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$OXID_{ACFuel}$
Data unit:	Fraction
Description:	Oxidation factor for the fuel used in aircraft engines
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data is local or regional

Data / parameter:	$OXID_{GenFuel}$
Data unit:	Fraction
Description:	Oxidation factor for the fuel consumed by the generator
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$NCV_{GenFuel}$
Data unit:	Mega Joule / mass or volume units
Description:	Net caloric value of the fuel consumed by the generator
Source of data:	Actual measured or local data are to be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$EF_{C,GenFuel, y}$
Data unit:	metric tons of carbon / mass or volume units
Description:	Carbon content of the fuel consumed by the generator
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$OXID_{TVFuel}$
Data unit:	Fraction
Description:	Oxidation factor for the fuel consumed by transport vehicles
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	NCV_{TVFuel}
Data unit:	Mega Joule / mass or volume units
Description:	Net caloric value of the fuel consumed by transport vehicles
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

Data / parameter:	$EF_{C,TVFuel, y}$
Data unit:	metric ton of carbon / mass or volume units
Description:	Carbon content of the fuel consumed by transport vehicles
Source of data:	Actual measured or local data should be used. If not available, regional data should be used, and in its absence, IPCC defaults can be used from the most recent version of the IPCC Guidelines for National Greenhouse Gas Inventories
Measurement procedures (if any):	Measurements taken according to best international practices
Monitoring frequency:	Yearly
QA/QC procedures:	
Any comment:	If the measurement results differ significantly from previous measurements or other relevant data sources, conduct additional measurements. Values must be compared to IPCC defaults if data are local or regional

6 EXPLANATIONS / JUSTIFICATIONS TO THE PROPOSED NEW BASELINE AND MONITORING METHODOLOGY

This section should be removed from the final version when it is approved.

6.1.1 Definitions

All the technical terms related to aircraft engines that are used within the methodology are defined.

6.1.2 Applicability conditions

This methodology is applicable to program type project activities that promote aircraft engine washing technologies. Applicable program activities are anticipated to rapidly promote and expand the project engine washing technology into the market by providing incentives to airlines. The applicable project category is:

- Transportation

Emission reductions are achieved by increasing propulsive efficiency as a result of engine washing. Other measures that may results in emission reductions (e.g., other efficiency measures, fuel switch, replacing aircraft engines, and improving combustion efficiency) are not covered by this methodology.

Providing incentives that are funded by carbon credit sales enables airlines that would not have washed their aircraft engines in a baseline scenario to participate in the program. Realizing that the project engine washing technology will quickly result in greater market penetration and, thus become common practice, the crediting period is limited to five years. The five-year-crediting period should be modified if the VCS Association considers it to not apply for this methodology.

There is no approved methodology (within VCS, CDM and Climate Action Reserve) for the same conditions of application.

6.1.3 Project boundary

The project boundary includes all the engines that are washed by the project engine washing technology including all flight routes.

All the major sources of emissions are included within the project boundary. CH_4 and N_2O emissions associated with combustion of jet fuel are not included as these emissions are negligible. This is consistent with 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

6.1.4 Identification of the baseline scenario

The baseline scenario is the existing level of fuel combustion efficiency or the amount of fuel that would be used by engines without the project activity. A modification to this baseline approach adjusts it to include the fact that approximately 5% of engines would have been washed anyway without program activities. In order to avoid establishing a complicated methodology to identify which specific engines would have been washed anyway (free riders), this methodology provides a discount factor. This approach is consistent with AMS II. J, version 3. The application of the discount factor to all project wash activities will discount resulting project emission reductions. This will allow all project washes to be assumed to provide emissions reduction benefit (albeit discounted), without concern that credit is unfairly being given to the 5% of washes that “would have happened anyway”.

AMS II. J is applicable for project activities that lead to efficient use of electricity through the adoption of self-ballasted compact fluorescent lamps to replace incandescent lamps in residential applications. A net-to-gross (NTG) adjustment factor (a default value of 0.95) is used in this methodology to account for a range of factors relevant to residential energy efficiency projects such as free-ridership and rebound effects. Though this proposed methodology is not for a small scale project, it takes a similar approach and proposes a baseline penetration discount factor of 0.90 indicated by the historic engine wash data of 5%.

6.1.5 Additionality

The methodology requires the CDM *"Tool for the demonstration and assessment of additionality,"* which consists with regulatory surplus, investment analysis, barrier analysis and common practice tests. This requirement is consistent with the VCS additionality guidance in the VCS 2007.1. Additionality demonstration needs to be done from the program organizer's perspective. As for project participants, as explained earlier, the methodology provides a discount factor to account for non-additional washes.

6.1.6 Baseline emissions

Baseline emissions are calculated as the estimated baseline fuel consumption multiplied by an emission factor. The baseline fuel consumption for an engine is estimated for each engine cycle, then aggregated by wash cycle, and finally the wash cycle fuel consumption is summed to get the annual fuel consumption per fleet.

It is common practice for airlines to track fuel consumption at the fleet level, but they do not track fuel consumption to the level of detail (per engine cycle) required to accurately calculate emission reductions per engine cycle. Due to this data limitation, this methodology allows project proponents to use modelled fuel consumption per engine cycle. Modelled fuel consumption is specific to the route travelled during the engine cycle and to the fleet being analyzed, and is calculated for the baseline case (in the absence of engine washing). Project proponents are required to use industry standard models that are routinely used within the airline industry to verify engine performance specifications.

Data limitations prevent an accurate comparison of modelled data to reported data. As stated, airlines track fuel consumption at the fleet level, and so it is possible to aggregate the modelled estimates of fuel consumption per cycle to the fleet level and compare it to the reported fleet level fuel consumption. However, airlines routinely implement other measures that will effect fuel consumption. These measures include instrumentation changes, software upgrades, engine maintenance or upgrades and weight reductions (such as installing lighter seats). Airlines do not routinely track the implementation of these measures. Since these measures can not be accurately accounted for, it is not possible to accurately verify modelled fuel consumption based on reported fuel consumption. Despite this, given the rigour with which these models are verified within the airline industry, the model outputs can be considered reliable.

According to estimates developed by Pratt & Whitney, approximately 500 engine washes occurred prior to P&W entering the wash market in 2004, all of which used the fire hose or Shepherd's Hook technology. Pratt & Whitney engine wash sales rose to 2,537 in 2008 and they anticipate washing approximately 3,000 engines in 2009. The commercial aviation market is estimated by Pratt & Whitney to have 40,000 jet engines and to achieve optimal performance and minimal emissions, each of these engines should be washed twice per year, for a total of 80,000 potential washes. Therefore, if 3,500 washes are delivered in 2009, (500 via old technology, 3,000 via project EcoPower® technology) total engine wash market penetration is 4.4% , and project market penetration is 3.75% Thus, 95% of engines are fully contaminated and remain so within (x months/years) of initial introduction into service.

Therefore, in the determination of $\Delta TSFC_m$ in section III it is acceptable to compare the engine trend data collected post-wash to engine trend data collected when the engine is fully contaminated.

6.1.7 Project emissions

Project emissions are calculated as the sum of emissions from fuel combustion during engine operation and the emissions associated with the washing process. Washing process emissions include those associated with energy use during the washing process and the transport of washing technology to aircraft terminals.

The emissions from fuel combustion during engine operation are calculated as the quantity of fuel consumed multiplied by the appropriate CO_2 emissions factor. As described in the baseline emissions section, models are used to derive fuel consumption per engine cycle in the baseline scenario (without engine washing). The estimate of baseline fuel consumption per engine cycle is aggregated to the wash cycle level, and this sum is then discounted by the average TSFC benefit realized during the wash cycle in order to calculate the project fuel consumption. Because modelled fuel consumption data are used for the baseline and project cases, the methodology does not need to take other fuel conservation measures that may result in reduce fuel consumptions into consideration.

Since the TSFC benefit is known for the first engine cycle in the wash cycle ($\Delta TSFC_m$) and this value declines linearly as the number of engine cycles approaches $ACFC_m$, it is possible to calculate the TSFC benefit of the last engine cycle in the wash cycle ($NEC_{j,wc}$) by looking at the proportion of $ACFC_m$ that is realized during the cycle. Once the beginning and ending TSFC benefit for the wash cycle is known, the average can be calculated.

The TSFC benefit following a wash is calculated based on the correlation between engine trend data and TSFC. This correlation uses established industry models that determine the relationship between engine trend data and TSFC improvements at various flight conditions. Project proponents establish the $\Delta TSFC_m$ value (as described in section III) for each fleet when an airline is first enrolled in the project and in the absence of changes in other factors that may improve TSFC (such as instrumentation changes, software upgrades, engine maintenance or upgrades), and these values are used for the entire crediting period. By eliminating these other factors from consideration, it is possible to focus only on the changes in TSFC that result from the engine wash and so the use of preset values results in a more conservative estimate.

In this methodology, the engines remain on-wing during the wash. Therefore, the washing equipment must be transported to the location of the engine. The emissions associated with transporting washing technology to the washing location are calculated as the distance travelled multiplied by the fuel efficiency of the vehicle and the appropriate emission factor.

During the wash, a generator is used to power the washing equipment. The emissions associated with running the generator are calculated as the energy consumption rate of the generator required to run the washing equipment multiplied by the length of time that a wash takes and the appropriate emission factor.

6.1.8 Leakage

There are no identified sources of leakage for this project.

6.1.9 Emission reductions

Rather than developing a speculative methodology to determine which engines would have been washed in the absence of the project, this proposed methodology provides a procedure to adjust emissions reductions based on a discount factor. This approach is the same as in AMS II.J, version 3.

Alternative approaches investigated include:

1: Ex-ante survey methods – This approach has been rejected by the CDM Executive Board in previous proposed CDM methodologies (i.e., NM0157 v.2.0) and so was not further considered here.

2: Control Group – Under this approach, the applicable engine wash market would be randomly separated into a control group and a project group. The control group would receive the standard marketing offering (without any mention of the carbon benefits) while the marketing effort directed at the project group would include the carbon benefits. Statistically significant differences in adoption rates between the two groups could therefore be attributed to carbon and thus identified as additional. However, the airline industry is quite small (there are approximately 20 airlines in United States) and this makes it highly unlikely that the control group would not hear of the carbon program, eliminating the separation between the two groups and skewing the results.

Since these methods have their own complications, the discount factor applied in AMS IIJ, version 3 was found to be the best available way to eliminate non-additional reductions. AMSIIJ, version 3 uses a discount factor of 0.95. To provide a more conservative estimate, a discount factor of 0.9 has been selected for this proposed methodology. This proposed discount factor is based upon the historical data as explained earlier.

6.1.10 Changes required for methodology implementation in 2nd and 3rd crediting periods

This methodology is only applicable for a crediting period of 5 years, with no renewal. Therefore, identification of changes is not necessary.

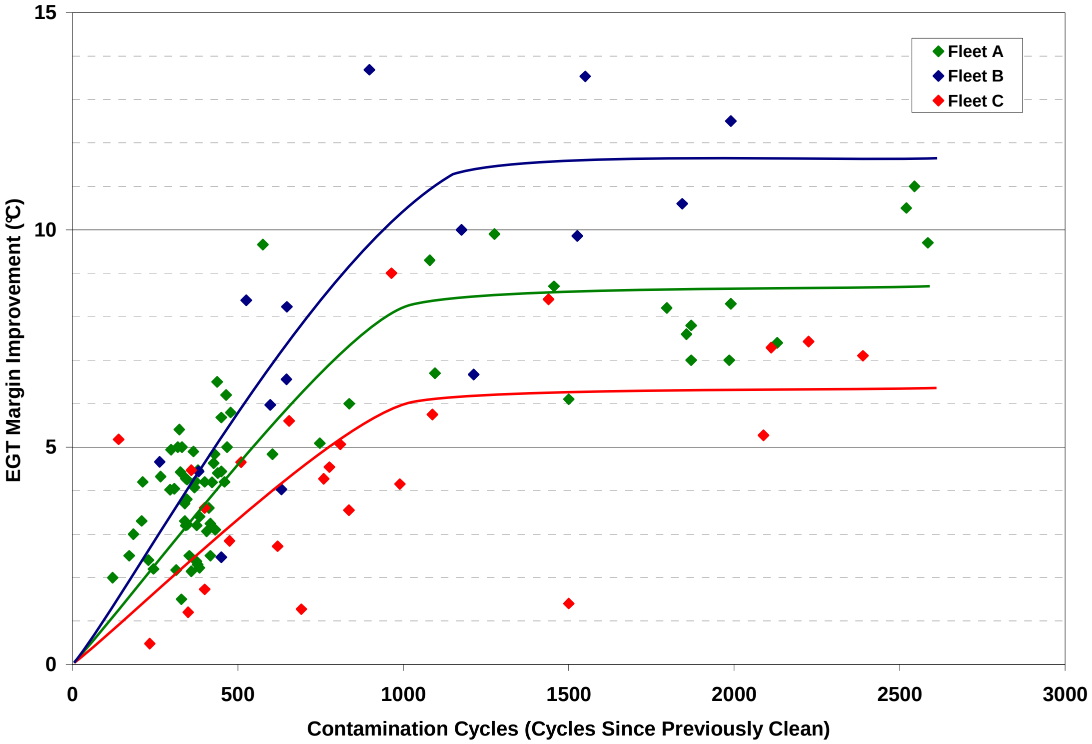
6.1.11 Monitoring methodology, including data and parameters not monitored

A key parameter in this methodology is the determination of how long it takes for an engine to become fully re-contaminated following a wash (in the absence of any subsequent washes), or $ACFC_m$ (see Appendix 1). This parameter could be specified relative to several variables, including the distance flown by an engine following a wash, the hours of operation for an engine following a wash or the number of engine cycles following a wash. However, previous analysis has found that engine contamination is more closely correlated with engine cycles, as opposed to distance or operating hours and so the parameter is specified in terms of engine cycles (see Appendix 1).

APPENDIX 1: ENGINE CONTAMINATION: TYPICAL CONTAMINATION INTERVAL AND CORRELATION TO CYCLES

Correlation of engine performance recovery (measured by reduction of engine fuel flow and exhaust gas temperatures) observed following an engine wash with the number of cycles flown by that engine since having previously clean compression system hardware (contamination cycles) has shown that the performance recovery of a wash follows a linear relationship with contamination cycles up to a threshold, where the performance improvement gains remain relatively constant with additional contamination cycles beyond that threshold. This characteristic, shown in figure 1 below, suggests that the airfoils in the engine reach a fully contaminated level, or saturation point, at which the airfoils do not continue to foul due to physical limitations.

Figure 1 – Performance Improvement as a function of Contamination Cycles



Pratt & Whitney's experience performing more than 8000 washes for 83 customers on 51 engine models and subsequent analysis has shown that engines typically reach a fully contaminated level between 800 and 1200 contamination cycles, with a few operators experiencing slower contamination rates, and rare instances when the rate is higher. The rate of contamination is dependent primarily on the environment which the engine is operated in. For example, engines operated in a sandy, salty, or polluted environment will likely become contaminated more rapidly than other engines.

Analysis of contamination rates observed by long-haul aircraft (cycle times ~6 hours or more) compared to short-haul aircraft (cycle time ~2 hours or less) have shown that contamination level is more highly correlated to the number of cycles flown than to hours of operation. This observation is consistent with our understanding of engine contamination as a function of environmental conditions. Since air is relatively clean at cruising altitudes, contamination would occur only during flight phases at low altitudes (takeoff/climb and descent/landing) and therefore correlate closely with cycles as observed.