ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1165440

AN IMPACT OF ENGINE DOWNSIZING ON CHANGE OF ENGINE WEIGHT

Zbigniew J. Sroka, Maciej Cieślak

Wroclaw University of Technology, Faculty of Mechanical Engineering
Wybrzeże Wyspianskiego Street 27, 50-370 Wroclaw, Poland
tel.: +48 71 3477918, +48 71 3204123
e-mail: zbigniew.sroka@pwr.edu.pl
cieslak.maciek@gmail.com

Abstract

One of the trends for development of internal combustion engine is downsizing, which in its final form leads to reduction of fuel consumption and limitation of carbon dioxide concentration in the exhaust gases. The obvious effect of reducing the volume of a cylinder is to reduce the dimensions of the various components, e.g. piston with rings and pin, connecting rod, crankshaft, engine block etc. Changes of geometric dimensions also affect the change in mass of each element and consequently − the whole engine. Expected weight reduction will be a benefit in considering downsizing techniques as another significant development trend in automotive applications associated with a reduction in the weight of the complete vehicle – called "light weight vehicle". The paper discusses the various forms of downsizing (by stroke, by diameter and mix) and their impacts on the changes in engine mass. The engine Subaru Flat 4, constructed with standard components in terms of design and materials was tested by virtual recognition in mass changes. Original drawings of components and sets have been simplified by for example does not account for chamfers and chops. When calculating also omitted the weight of typical accessories (e.g. fuel lines or electronic components), assuming that each considered option has the same equipment. The highest change in the weight of minus 7.27 % relative to the standard engine was done with downsizing by diameter and smallest one (-6.09 %) by downsizing mix.

Keywords: *combustion engine, downsizing, weight change*

1. Introduction

The prospect of the presence of internal combustion engines as the dominated powertrain for transport means and their continuous development is dictated by the adoption of a sustainable transport strategy. It assumes the differentiation of drive systems through participation in electric one or mixed, but fill everyone's expectations is not always possible due to the advancement of knowledge, technology development and due to financial constraints. In the case of hybrid and full-electric drive, do not meet expectations for run comfort by too frequent recharging and therefore limit the use primarily to urban conditions. An important limitation is the still high price of manufacturing and operating costs, despite the obvious ecological advantages [12-14, 17]. On the other hand, in the case of fuel cells are still not resolved issues of the proper selection of the type of cell structures and operating conditions. There are also unknown elements of the reliability of fuel cell systems and still lack adequate infrastructure maintenance this type of drive to match the standards at the level of use of internal combustion engines [1, 11].

The emergence of new technical possibilities e.g. dynamic control of the combustion process in internal combustion engines, burning very poor fuel-mixtures or the use of alternative fuels make the dominance of internal combustion engines will continue and further scenarios of their development will change.

Some of the important trends of development of internal combustion engines include downsizing to be that by reducing the volume of displacement leads to reduced fuel consumption and carbon dioxide emissions to the atmosphere while maintaining performance. This means an increase in specific power as one of the important indicators of the engine. Downsizing in its simplicity provides a very good relationship generated effects to the costs of its implementation. Reducing the swept volume of internal combustion engines already existed in fact, when the market is seeing increasingly smaller engines that offer similar characteristics and lower fuel consumption. Such knowledge is not systematic, and single studies are rarely described in the literature, although it should expect them to intensify due to the so-called *the second generation of downsizing* [4, 5, 10].

In previous papers [6-9, 18, 20] the changes of engine displacement in relation to the downsizing expressed by the relation volume after to before changes and sometimes called *the degree of downsizing* or *downsizing ratio* (DR). There are also research that link changes in the geometry to changes of indicators of work (mean effective pressure), showing the so-called *global changes downsizing* [15]. Regardless of the description form, the point of reference for any analysis is the change in volume, which represents the percent reduction in the volume of a cylinder of an engine base. On this basis, it is determined by changes in volumetric indicators, such as volumetric power and torque or emission of carbon dioxide per volume unit.

Meanwhile, the swept volume is a design parameter that can be expressed by stroke and cylinder diameter as elementary geometric components, which means that their mutual combination, may cause the same change in volume but indirect effects may be different.

In this way, different types of downsizing can be defined, as follow:

– **downsizing by stroke**, where only changes the stroke,
– **downsizing by diameter**, which changes only the diameter of the cylinder,
– **downsizing mix**, where are changed both bore and stroke.

In Fig. 1, it shows a graphical interpretation of the types of downsizing.

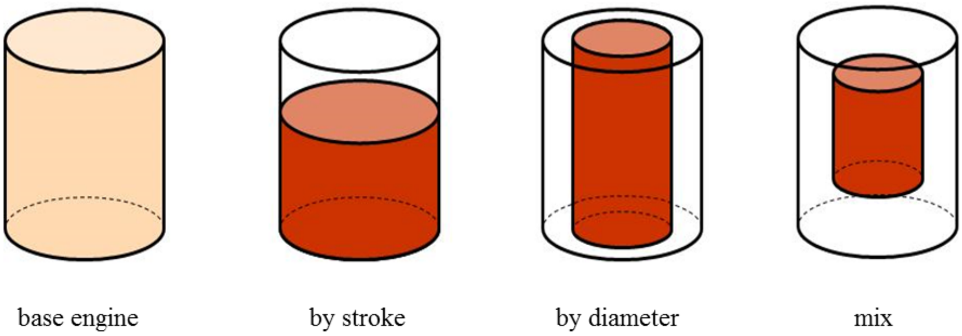

Fig. 1. Types of downsizing [16]

If the swept volume (V_{ss}) is treated with a cylinder, it may be described by equation:

$$V_{ss} = S\frac{\pi D^2}{4}i, \tag{1}$$

where:

S – stroke,
D – diameter of the cylinder,
i – number of cylinders.

Taking into account relationships between volume and stroke and bore, and assuming the same number of cylinders $i_d = i$, downsizing can be defined as follows:

$$DR = \frac{V_{ssd}}{V_{ss}} = \frac{S_d\frac{\pi D_d^2}{4}i_d}{S\frac{\pi D^2}{4}i} = \frac{S_d}{S}\left(\frac{D_d}{D}\right)^2, \tag{2}$$

where:
V_{ssd} – engine displacement after downsizing,
V_{ss} – engine displacement before downsizing,
S_d – stroke after downsizing,
S – stroke before downsizing,
D_d – bore after downsizing,
D – bore before downsizing,
i_d – number of cylinders after downsizing,
i – number of cylinders before downsizing.

If the relationship between stokes labelled as "A" and the relationship between the diameters as "B" then receives (3):

$$A = \frac{S_d}{S}, \quad B = \frac{D_d}{D} \tag{3}$$

and then (2) takes the form (4):

$$DR = AB^2, \tag{4}$$

In order, however, that this relationship is not determined the level of residues, but the degree of change should be taken (5):

$$W_d = 1 - AB^2. \tag{5}$$

Equation (5) gives the general form of change of engine displacement and called downsizing factor "W_d".

The thermodynamic consequences by downsizing approach are described in literature [16]. The effect of reducing the swept volume is to reduce the dimensions of the various components, e.g. piston with rings and pin, connecting rod, crankshaft, the cylinder block etc. Geometric changes impact on the changes of the masses of each element and consequently the whole engine. This may occur both in the case where the process of downsizing will be accompanied by changes in materials, but also when, due to mechanical or thermal loads occur need to change the material. Expected weight reduction will be a benefit in considering downsizing techniques with another – equally important trend in automotive industry development associated with a reduction in the weight of the complete vehicle – called *lightweight vehicle* [2, 3, 19].

2. Assumptions to assess the impact of downsizing on the change of engine weight

To verify explores the effects of changes in the engine displacement (by changing the cylinder bore and stroke), changes of the weights of parts and the whole engine it uses a virtual model-flat boxer engine Subaru. This engine has four cylinders with a total displacement V_{ss} = 2.699 dm^3. Volume changes were made by the three types of downsizing shown in Fig. 1.

Adopted the following options designations:

Option 1 – downsizing by stroke, where reduced stroke of S = 86 mm to S_d = 65 mm. Changing crank also forced to change the height of the cylinder with a water jacket. The displacement of the engine after the change was V_d = 2.041 dm^3, which means that the downsizing factor is W_d = 0.24.

Option 2 – downsizing by diameter, made by reducing the cylinder diameter D = 100 mm to D_d = 88 mm, resulting was to change the displacement volume of V_{ss} = 2.699 for V_{ssd} = 2.091 dm^3 and W_d = 0.23.

Option 3 – downsizing mix, where the change in piston and stroke realized by changing the length of the crank of the crankshaft with a nominal value of S = 86 mm to S_d = 80 mm and by reducing the bore D = 100 mm D_d = 90 mm. Received engine swept volume V_{ssd} = 2.034 dm^3 and downsizing factor was W_d = 0.25.

Mentioned above options show that the downsizing factors are comparable and therefore the effect of changing the weight will refer to the same change in displacement. The main engine units were evaluated with assumption that the remaining systems will not have a significant impact on weight change. Likewise not included in the calculation the weight of additional equipment (like fuel pipes, electrical wires etc.) which in each of the three variants could be the same. In addition, any chamfer or design curves resulting from the drawings, were ignored. Not taken were also into account seals between parts and assemblies. Therefore, the following sets were analysed:

– engine block, made of aluminum alloy having a specific gravity 2.710 kg/dm^3,
– cylinders with a water jacket made of iron alloy (7.250 kg/dm^3),
– crankshaft, made of steel (7.850 kg/dm^3),
– piston set with connecting rod, where the piston was made of aluminum alloy (2.710 kg/dm^3) and the connecting rod of carbon steel having a specific gravity of 7.850 kg/dm^3.

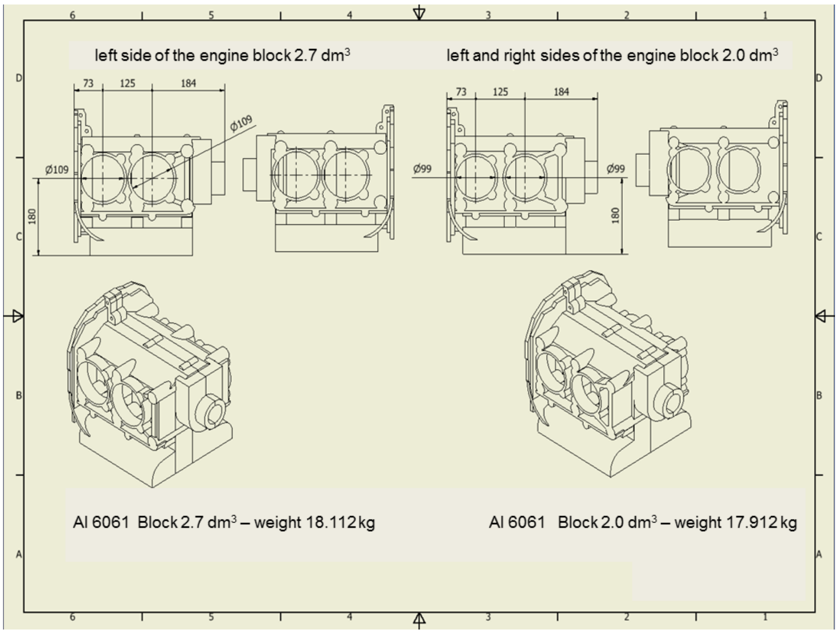

Fig. 2. Engine Subaru Flat4 – simplified assembly drawing

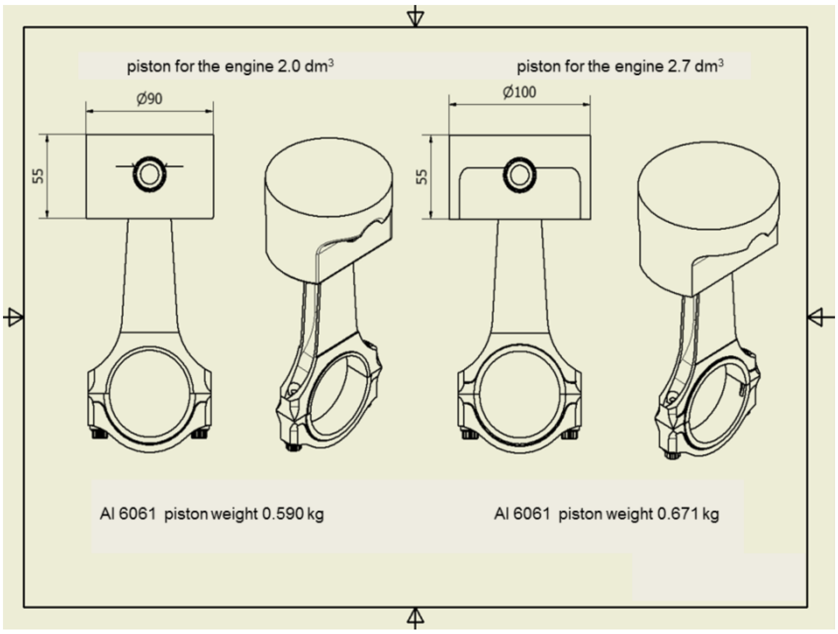

Fig. 3. An example of the simplified geometric drawing of piston of Subaru Flat4 engine for Option 3

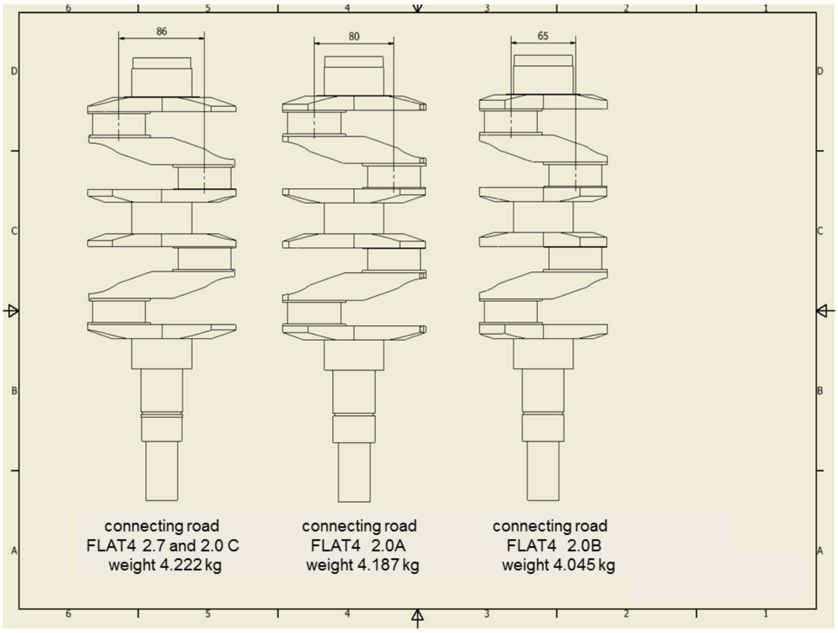

Fig. 4. A simplified geometrical drawing of connecting rod Subaru Flat4 engine for all options

3. Test results

The mass of selected components/sets for nominal (base) engine i.e. before downsizing and for the mentioned options labelled 1, 2 and 3, with the percentage of specifying changes in the mass are shown in Tab. 1-3.

Tab. 1. Masses of components/sets for Option 1

Component/set	Mass [kg]		Relative change in weight after/before [%]
	Before	After	
Engine block	18.26	18.26	0.00
Cylinder with water jacket	4.12	3.37	–18.29
Crankshaft	12.23	11.73	–4.09
Piston set	1.00	1.00	0.00

Tab. 2. Masses of components/sets for Option 2

Component/set	Mass [kg]		Relative change in weight after/before [%]
	Before	After	
Engine block	18.26	18.03	−1.28
Cylinder with water jacket	4.12	3.35	–18.71
Crankshaft	12.23	12.23	0.00
Piston set	1.00	0.91	–9.66

Tab. 3. Masses of components/sets for Option 3

Component/set	Mass [kg]		Relative change in weight after/before [%]
	Before	After	
Engine block	18.26	17.91	–1.90
Cylinder with water jacket	4.12	3.54	–14.12
Crankshaft	12.23	12.13	–0.83
Piston set	1.00	0.92	–8.17

Assessed four-cylinder engine has four sets with four piston and four cylinders giving following weights:
– base engine: 50.99 kg,
– engine option 1: 47.48 kg, reduction by 6.90%,
– engine option 2: 47.29 kg, reduction by 7.27%,
– engine option 3: 47.89 kg, reduction by 6.09%.

4. Summary

By example of the Subaru engine Flat4, built with typical components and sets in terms of both construction and material can be concluded that the reduction of the displacement reduces the weight of items, sets and weight of the whole engine. For the analysed engine, the biggest change in weight was recorded along with a reduction in the volume according to the principles of downsizing by diameter (option 2). This change was minus 7.27%. In turn, the smallest change in engine weight (–6.09%) was done by downsizing mix. The given example illustrates the possibilities for reducing engine weight as benefit for downsizing.

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