MASS AS A "WHAT IS TRANSPORTED" TERM IN EFFICIENCY STANDARDS

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ABSTRACT

Recent ICAO deliberations have highlighted some of the tradeoffs faced by including or excluding aircraft and/or fuel mass in an aircraft efficiency metric. This paper introduces the U.S. Corporate Average Fuel Economy (CAFE) program for passenger vehicles as a case study to demonstrate how metrics that include vehicle and/or fuel weight could potentially relax incentives for manufacturers to devote technological improvements to reducing fuel consumption rather than boosting performance. In addition, we show how the behaviour of metrics that include non-payload mass elements may diverge from real vehicle and fleetwide efficiency trends where large increases in vehicle performance occur over time.

INTRODUCTION

Recent deliberations within ICAO on developing an aircraft CO_2 standard have identified differences of opinion in how mass should be defined in a metric, namely, the tension between the possible inclusion of aircraft and/or fuel mass in the denominator of a metric for normalization purposes versus the development of a metric that defines payload capacity directly through aircraft weights such as maximum zero fuel weight (MZFW) and manufacturer empty weight (MEW).

In general terms, advocates of a payload-only approach note that only metrics using payload as the WIT parameter can be expected to accurately and consistently credit improvements in technology.[1] In contrast, supporters of continuing to analyze metrics involving aircraft and/or fuel mass noted that payload mass is less correlated with fuel efficiency than total aircraft mass and raised concerns that the inclusion of payload in a metric could introduce opportunities for gaming.

Since the primary goal of an ICAO CO_2 standard is to promote more fuel-efficient aircraft in the future, a forward-looking focus is appropriate. It is also useful to consider the history of efficiency standard-setting in other modes to see what lessons can be learned from those efforts. This paper uses the US Corporate Average Fuel Economy (CAFE) program for passenger vehicles to illustrate a possible outcome of including aircraft and/or fuel mass in a metric; that is, sacrificing a level of certainty that the gains of technological improvements will be devoted to reducing emissions rather than boosting vehicle performance.

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[1] Payload metrics can also reward greater design optimization, while metrics incorporating takeoff weight or useful load could undervalue or even punish manufacturers that reduce fuel burn by better matching aircraft capabilities to real-world operational missions. See "Comparing the Environmental Effectiveness of Candidate Metrics and Test Points", ICCT, 2010. Available at http://www.theicct.org/2010/06/comparing-metrics/.

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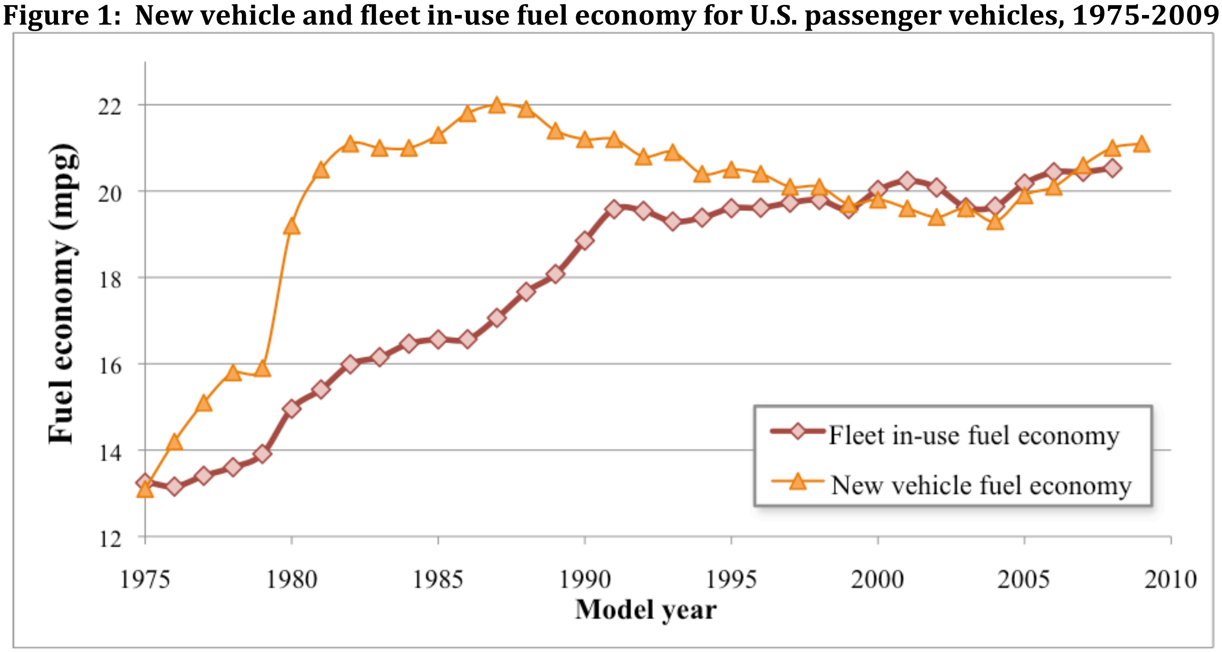
While helpful, ICAO discussion on the merits and demerits of WIT parameters has failed to reflect that fact that metrics that incorporate vehicle and/or fuel weights may be less environmentally effective than payload-based metrics because they would relax incentives to devote improvements in technology to reducing emissions as opposed to boosting vehicle performance. Where improvements in technology (e.g. lightweight materials, improvements in engine and/or drive train efficiency, reduced aerodynamic drag, etc.) are devoted to increasing maximum vehicle capabilities rather than to reduce fuel consumption, metrics that include vehicle mass are likely to show improvement that is not reflected in the fuel consumption either of that given vehicle or the broader fleet as a whole. This can best be demonstrated by reference to trends in passenger vehicle fuel economy in the United States between the early 1980s and 2005 under the U.S. Corporate Average Fuel Economy (CAFE) standard.

The CAFE program, which was adopted in 1975 as part of US efforts to reduce its petroleum dependence, established corporate average fuel economy targets by vehicle class, with separate miles per gallon (mpg) targets for cars and light trucks. The separate light-truck target was established because at the time the CAFE program was established there was very limited penetration of light trucks, SUVs, and minivans in the general vehicle population and was thus intended in essence to cover vocational work trucks.

Through 1982, CAFE proved successful in promoting new vehicle fuel economy (Figure 1). After 1982, average new vehicle fuel economy stagnated because standard levels were not revised and improvements in engine and drive train efficiency began to be increasingly used to boost vehicle performance (e.g. 0 to 60 acceleration), vehicle size, and vehicle weight. Increases in vehicle size and weight were partially a result of a systematic shift in the sales of new vehicles towards light trucks, minivans, and SUVs, which were covered by more lenient standards under CAFE's binned standard approach. New vehicle fuel economy fell after the late 1980s, and by the late 1990s new vehicle fuel economy and the on-road fuel economy of the in-service fleet had converged.

Figure 1: New vehicle and fleet in-use fuel economy for U.S. passenger vehicles, 1975-2009

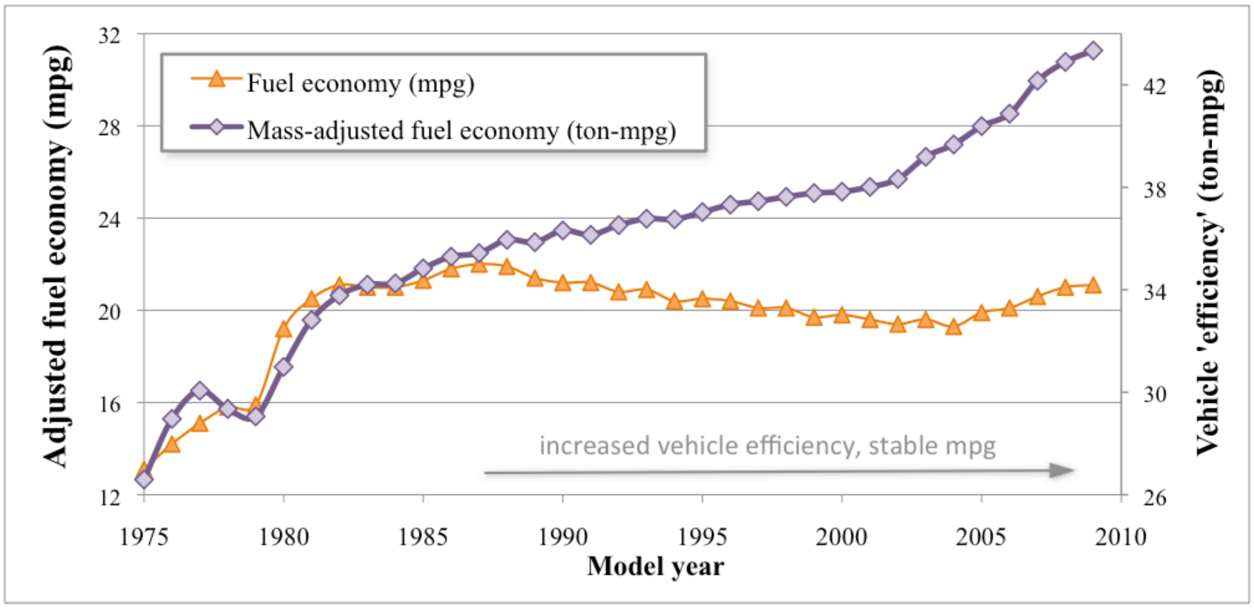


Sources: US EPA. 2010. Fuel Economy Trends: 1975 Through 2009. (new vehicles); U.S. DoE. 2010. Transportation Energy Data Book. (fleet in-use).

Had the CAFE targets been strengthened over time, or been revised so as to minimize the light-truck loophole, increases in new vehicle fuel economy to 1982 could have been sustained and extended. This can be seen by comparing fleet performance on a simple mpg metric versus that of a hypothetical metric of mpg-ton of vehicle mass, measured in terms of inertial weight.[2] Multiplying mpg by inertial weight creates a metric that, when inverted, strongly approximates the behaviour of a mission-based metric using takeoff weight (TOW) as the WIT normalization metric (FEM.22).

Figure 2 shows the relationship between the actual CAFE mpg metric and a hypothetical ton-mile/gallon metric for US passenger vehicles over the past 35 years. As Figure 2 demonstrates, starting in 1982 there was a divergence between a mpg and ton-mpg metric for passenger vehicles, with the ton-mpg metric continuing to improve more or less continuously over time even as the mpg metric stagnated. This trend is due to the fact that the efficiency of engines and drive trains continued to improve even as vehicle size, mass, and performance increased and compromised fuel economy at the vehicle level.

Figure 2: New vehicle mpg and ton-mpg efficiency for U.S. passenger vehicles, 1975-2009



Sources: US EPA. 2010. Fuel Economy Trends: 1975 Through 2009.

Comparing Figures 1 and 2 shows that the hypothetical ton-mpg metric, which includes vehicle and fuel weight, fails to accurately predict trends in both new and on-road fuel economy because improvements in underlying technology were devoted to increasing vehicle performance rather than reducing fuel consumption and emissions. In general terms, the inclusion of vehicle and fuel mass in an efficiency metric can provide a weakened incentive for manufacturers to reduce emissions at the vehicle level that can, under extreme circumstances, lead to a stagnation or even backsliding of efficiency.

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[2] The definition of inertial weight varies by regulatory agency. US EPA defines an "inertia weight class" as curb weight plus 114 kg plus a variable amount of weight to fit a given car into an inertial "bin" (on average, in 2009 an additional 43 kg). Curb weight denotes the actual or the manufacturer's estimated weight of the vehicle in operational status with all standard, fuels (full tank of gas), and lubricants, and with the computed weight of some optional equipment. See EPA420-B-00-001, February 2000.

DISCUSSION

One must be careful when extrapolating the experience of the CAFE program to efficiency standards for aircraft. While individual drivers systematically undervalue the fuel savings associated with energy efficiency, airlines, the first customers of commercial aircraft, are clearly more fuel price sensitive. Given natural market pressures for lighter aircraft, it seems unlikely that a systematic upward trend in aircraft mass such as that observed in US passenger vehicles will occur unless that weight is enabling some other critical aircraft performance parameter that is also valued by airlines.

That being said, for aircraft, reductions in SFC, aerodynamic drag, and structural weight can be used to meet a number of competing objectives, of which fuel burn over a given mission is just one. For aircraft, performance goals that compete most directly with fuel efficiency include range, payload, and speed, although it has also been recognized that other aircraft design criteria such as takeoff field length, climb performance, etc. are also important. Given the large fuel fractions of aircraft relative to other vehicle modes, using parameters such as useful load or takeoff weight that incorporate fuel mass to normalize fuel burn in a metric or correlating parameter may exacerbate potential tradeoffs between fuel efficiency and aircraft performance given that fuel is in effect treated as payload.

On a related note, some WG3 members have expressed a desire to develop an aircraft CO_2 metric that focuses only on technology. While metrics including basic measurements of technological efficiency such as L/D and SFC were initially considered by the MAPah group, they have since been red-carded due to concerns about the proprietary nature of data that would have needed to be certified. Given that, it appears unlikely to us that an aircraft-based metric that isolates technology alone can actually be developed given the large number of aircraft design parameters in play. It is true, however, that some metrics and associated correlating parameters are more likely to “control” vehicle design parameters than others. Those metrics are likely to include airframe and/or fuel mass as normalization parameters and will be vulnerable to the trends identified in this paper.