TEST CYCLES USED TO EVALUATE VEHICLE EFFICIENCY

Dan Rutherford, Ph.D.
Mazyar Zeinali, Ph.D.

International Council on Clean Transportation

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ABSTRACT

One key component of a CAEP/9 CO_2 certification requirement and standard will be the test point(s) used to evaluate the efficiency of aircraft. This paper surveys the range of test cycles used to evaluate the efficiency of vehicles – including passenger cars and trucks, motorcycles, heavy-duty trucks and buses, and marine vessels – in order to inform ICAO discussion of a CO_2 certification procedure.

This paper shows that efficiency test cycles covering a variety of transport modes typically test vehicles at points representative of operational norms rather than at maximum vehicle capabilities. Testing the efficiency of vehicles near operational norms provides optimal incentives for the adoption of technologies and designs that reduce fuel consumption during real-world operation. In addition, we discuss differences between transient and steady-state test cycles and relate those differences to mission-based and point performance metrics currently under discussion.

INTRODUCTION

One key component of a CAEP/9 CO_2 certification requirement and standard will be the test point(s) used to evaluate the efficiency of aircraft under a standard. While some WG3 members have conducted research on real-world aircraft operations to inform the choice of evaluation options, there is not yet a commonly accepted understanding of how test point(s) for a CO_2 certification requirement and standard should be chosen.

One current point of contention within the TG concerns is whether the efficiency of aircraft under a standard should be evaluated at point(s) meant to represent actual operations or at the aircraft's maximum capabilities in terms of payload and range. The former approach would likely involve testing aircraft at point(s) well below their maximum capabilities in terms of payload and range.

This paper discusses a variety of test cycles used to evaluate the efficiency of vehicles worldwide, including passenger vehicles, motorcycles, heavy-duty (HD) trucks and buses, and marine vessels, in order to inform TG discussion of a CO_2 certification procedure.

ANALYSIS

Vehicles are used under a variety of operating conditions, and testing their efficiency in the field can be complicated and resource intensive. For this reason, efficiency standards evaluate the efficiency of vehicles on standardized test cycles generally meant to approximate the range of operating conditions that a vehicle encounters in-use.

In order to facilitate a discussion of this technical issue, we offer the following definitions of key terms:

a) *Duty cycle*: the actual range of operating conditions a given vehicle encounters in-use. Duty cycle will vary by vehicle type, model, usage/function, and driver within certain bounds.

b) *Test cycle*: a series of test routines that specify a vehicle's operating parameters (load, speed, acceleration, grade, etc.) at each point in time of a certification test.

c) *Transient (test) cycle*: a test cycle with changes in operating parameters over time. Urban test cycles for road transport are uniformly transient.

d) *Steady-state (test) cycle*: a test cycle where operating conditions remain constant over time. Some, but not all, highway test cycles are steady-state.

In its work on efficiency standards, the International Council on Clean Transportation (ICCT) has gained familiarity with a variety of test cycles used worldwide as a part of vehicle efficiency standards. This includes passenger vehicle test cycles in Europe, the US, and Japan; test cycles for HD trucks and buses in Japan; motorcycle test procedures in Taiwan, and the "test cycle" for the IMO's EEDI.

While a full description of the detailed test procedures[1] is beyond the scope of this document, it is possible to summarize and compare some key operating parameters that define these test cycles. The results of this simple comparison are shown in Table 1 in terms of the range of operating parameters such as load, speed, acceleration, and grade for a variety of modes, both in absolute terms and, where possible, as a percentage of maximum capabilities.

As Table 1 shows, across a broad range of countries, regions, and modes, vehicle efficiency is typically tested near operational norms that diverge significantly from maximum capabilities. In summary:

a) Mass loads: Payloads of 25~50% of maximum, except in the case of IMO's EEDI (100% default, 65% for container ships).

b) Speeds: Average test cycle speeds are 20~75% of maximum capabilities. Test cycle speeds for on-road transport peak at approximately 60% of maximum vehicle capabilities.

c) Acceleration: Maximum accelerations experienced under test cycles for cars and light trucks range from 33 to 43% of maximum potential.

d) Grade: In one case, a highway test cycle for heavy-duty trucks, simulated maximum grades derived from Japan's busiest expressway slowed a half-loaded test truck to approximately 1.5% below the targeted steady-state test speed of 90 km per hour.

Table 1 also illustrates the limited role that steady-state test cycles have traditionally played in vehicle efficiency standards. With the exception of IMO's EEDI, where a steady-state test at 75% rated speed has been adopted as the default test point for marine vessels, all efficiency standards

[1] For example, for passenger cars and trucks a full certification procedure would include guidance on auxiliary loads, accessory operation, tire selection, ambient temperature, preconditioning, cooling air, etc.

being implemented today are at least partially evaluated under transient conditions, reflecting the fact that real-world operations can vary considerably from any idealized point of operation. Including a transient component to a certification procedure provides additional confidence that the proper mix of technologies and designs will be rewarded under a given standard, particularly for conventional pollutant emission standards.

DISCUSSION

Table 1 highlights that, while there is diversity in the exact test procedure used from mode to mode, vehicles are rarely evaluated near their maximum capabilities where operational norms diverge. In the few cases where a test cycle approaches a vehicle's maximum capabilities (e.g. grade under Japan's HD highway test cycle), it did so because those conditions are expected to be encountered in real operations. Testing the efficiency of vehicles near operational norms provides optimal incentives for the adoption of technologies and designs that reduce fuel consumption during real-world operation.

Among the various standards surveyed here, the IMO's EEDI comes closest to evaluating a vehicle near its maximum rated payload (default 100% of deadweight tonnage or, in the case of passenger ships, gross tonnage). Note that the EEDI is still open for revision, and countries may yet bring technical studies forward that show that a test point below 100% is appropriate for certain ship types. Such an analysis led to the decision to use 65% of deadweight tonnage as an evaluation point for container ships in order to avoid suboptimal designs.

Whatever the vehicle, it is normal for manufacturers to market products with a substantial margin of maximum capability to typical use – the divergence between operational patterns and maximum capability identified in previous TG work is not unique to aircraft. Reasons why manufacturers market "excess" vehicle capabilities include the ability to cover a broad market segment with a standardized product, offering consumers flexibility to cover a large range of possible trips, and to appeal to consumers that value potential performance for its own sake. For example, passenger cars are marketed based upon the maximum number of passengers they can carry, which may be quite different from typical use.

The results outlined in Table 1 are relevant to ongoing discussions within WG3 about possible representative test point(s) for a certification requirement. While work is ongoing, BTS operations data suggests that using loads of around 55% maximum structural payload (MZFW-OEW) and an average flight distance of approximately 0.3 R_1 range is a starting point for evaluation options that approximate real operations. These values are a fraction of maximum aircraft capabilities, which is consistent with test cycles used for efficiency standards in other transport modes.

Among the options being discussed within the CO_2 TG, point performance metrics such as specific air range (SAR) evaluated at an optimized speed such as MRC or LRC most closely approximate a steady-state test cycle. For aircraft, landing and takeoff, climb, and descent represent transient operating conditions; thus, mission-based metrics being considered by the MAPah group can be understood as representing a transient test cycle.

Table 1: Selected Operating Parameters by Test Cycle

Country /region	Mode	Test cycle	Relevant performance variables (% of max)					
			Payload/ Capacity	Speed		Max acceleration	Grade	
				Average	Max		Average	Max
US	Passenger vehicles	CAFE	157 kg (~30%)	43 km/hr (24%)[1]	96 km/hr (53%)[1]	5.3 km/hr/s (43%)[2]	-----	-----
EU-27	Passenger vehicles	NEDC	100 kg (20%)	34 km/hr (19%)[1]	120 km/hr (67%)[1]	3.8 km/hr/s (~33%)[2]	-----	-----
Japan	Passenger vehicles	JC08	110 kg (~40%)	24 km/hr (13%)[1]	82 km/hr (46%)[1]	6.1 km/hr/s	-----	-----
	HD vehicles	Urban mode	50%	~30 km/hr (23%)[1]	85 km/hr (65%)[1]	~3 km/hr/s	-----	-----
		Interurban mode	50%	80 km/hr (62%)		-----	0%	5%
Taiwan	Motorcycles	ECE-15	75 kg	19 km/hr (19%)	50 km/hr (50%)	3.7 km/hr/s	-----	-----
		Steady state	75 kg	50 km/hr (50%)		-----	-----	-----
Global	Ocean-going vessels	IMO EEDI	100% default[3], 65% for containers	75% of MCR		-----	-----	-----

[1] Reference max speeds: PV: 180 km/hr; HD: 130 km/hr; Motorcycle 100 km/hr.
[2] Calculated as % of 0 to 60 mph acceleration time.
[3] Not yet finalized – may be revised for additional ship types.
Sources: ICCT 2007, 2009; METI/MLIT 2005; EPA 2010; Dieselnet 2000.