Allison Transmission
EPA Meeting

May 19, 2011
Ann Arbor, MI

Agenda

- Introductions – Debbie Gordon
- Update on Rulemaking – EPA
- Allison Summary Points – Debbie Gordon
- Transmission Spec'ing for Fuel Economy – Debbie Gordon
- Hybrid Discussion – George Pelton
- Drive Cycle Weighting – Debbie Gordon
- Allison Test Experience and Lessons Learned – Curt Vapor
- EPA Test of 2000 Series™ – EPA
- Wrap-up

Allison Transmission - EPA Meeting

Purpose:

1. Discuss EPA/NHTSA intent for upcoming Fuel Efficiency Regulations for MD/HD Vehicles
2. Discuss Allison views on various topics

Process:

Presentation with open discussion

Product:

1. EPA have a better understanding of Allison views
2. Allison have a better understanding of EPA/NHTSA direction
3. Follow-up items if required

May 19, 2011 Attendees

Allison

Debbie Gordon

Bob Leopold

Kevin Rodgers

Curt Vapor

Mark Janson

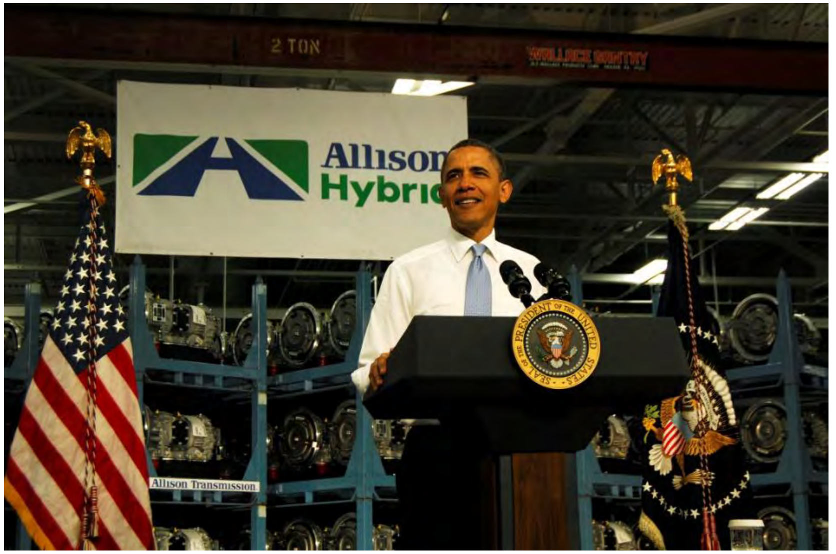
George Pelton

Crowell & Moring

Bob Meyers

President Obama Visits Allison: May 6, 2011

"What you're doing here at Allison Transmission is really important. Today there are more than 3,800 buses using (your) hybrid technology all over the world…… soon, you'll be expanding this technology to trucks as well….. That means more jobs here at Allison. Last month, you added 50 jobs at this company and I hear that you plan to add another 200 over the next two years. So we are very proud of that. "



"I don't want the new breakthrough technologies and the new manufacturing taking place in China and India. I want all those new jobs right here in Indiana, right here in the United States of America, with American workers, American know-how, American ingenuity."

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Allison Summary Points

Allison Summary Points

Vertical Testing

- The effect of transmission on the emission of GHGs and FE cannot be accurately assessed in isolation, but can only be assessed with respect to the entire vehicle system.
  - Work done must represent net calculation of work, not just positive work
  - Testing must be tightly controlled to ensure integrity of results; tests must produce results that are actually representative of real-world vehicle configurations and performance.
  - Powerpack testing may not represent a realistic integrated vehicle system unless special care is taken to account for system level effects to achieve real world results.

- EPA must take the necessary time to "get it right." EPA should not finalize any overly simplistic testing protocol for transmissions, but instead exclude transmissions as originally proposed.

Allison Summary Points

Drive Cycle

- EPA received numerous comments on drive cycles, particularly for vocational vehicles. Most comments agreed that the cycles did not reflect real world operation of the vehicles and that steady-state cruise was over-represented in drive cycles and transient operation was under-represented.

- Final rule can be improved by:
  - Ensuring that drive cycles are weighted based on time – not distance.
  - Measuring vehicle impact on GHGs/FE through assessment of the actual distance traveled on the drive cycle in the time prescribed in the drive cycle
  - Including grades within drive cycles
  - Include vocational subgroups (Allison-suggested approach)
  - NOT including straight line acceleration in GEM drive cycles. Straight line acceleration does not reflect "natural acceleration" curves. Straight line acceleration is not "technology neutral" but contains bias towards AMTs.
  - Utilizing European-type approach for drive cycles.

Allison Summary Points

Hybrid Testing/Innovative Technology Program

- Any "A to B" testing must use common vehicle configurations, as actually built by OEMs for the "A" vehicle. The "B" configuration must be the exact configuration of the hybrid or innovative technology intended to be produced. Vehicle system must include:
  1. Engine, engine calibration, and after-treatment system but no regen during testing.
  2. Automatic transmission system must replicate the actual, integrated vehicle system including torque converter, gear set, shift schedule, axle, cooling system load, electrical system/accessory loads.
  3. Manual/AMT transmissions must include the clutch, gear set, controls/calibration, axle, cooling system load, electrical system/accessory loads.
  4. Hybrid system representative hybrid components, energy storage, powertrain, drivetrain, calibrations, axle, cooling system load, electrical system/accessory loads.

Allison Summary Points

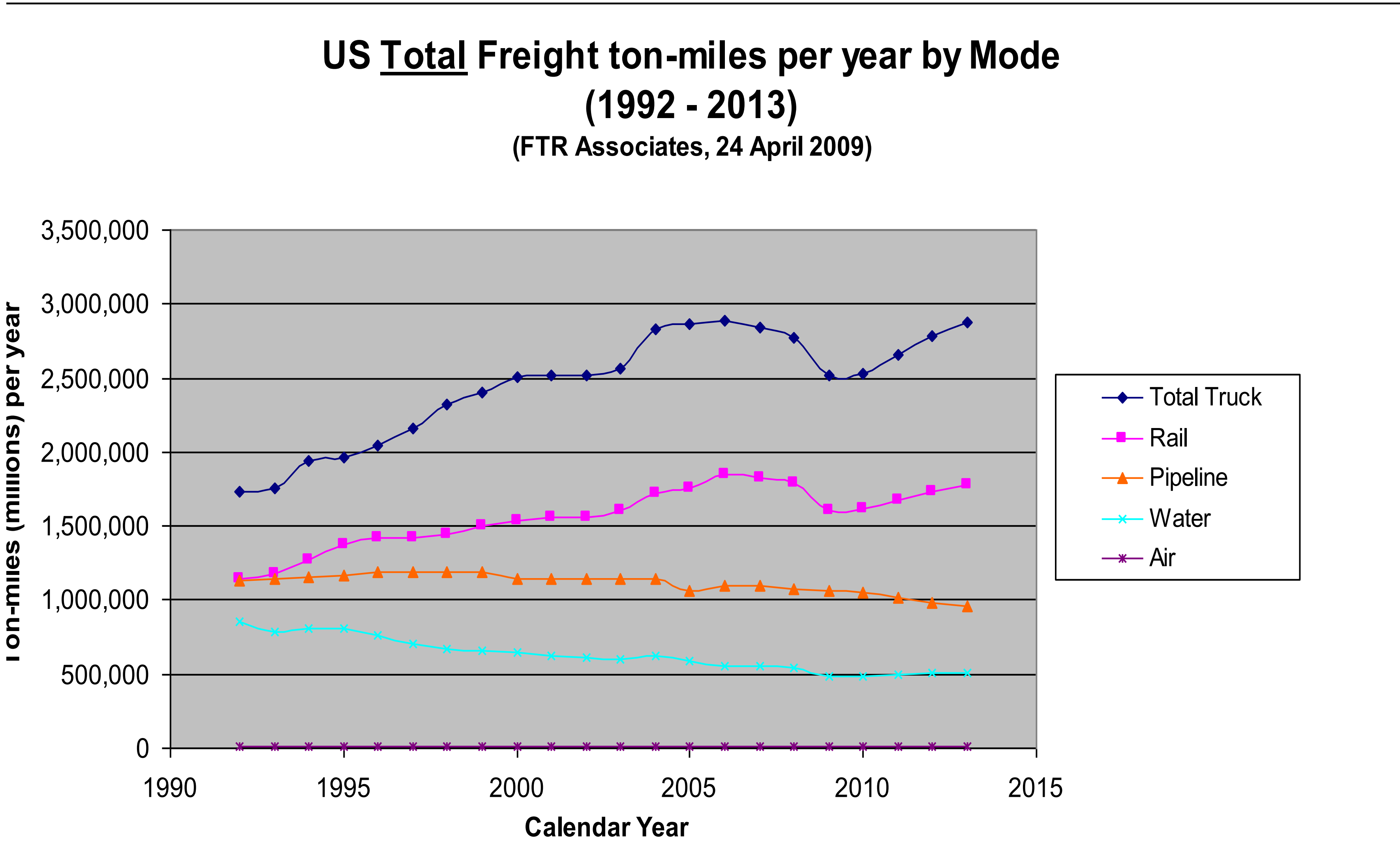
Hybrid Testing/Innovative Technology Program

- Hybrid Drive Cycles need to be substantially revised from those contemplated in proposed rule; need to include additional transient operation and account for grades.
  - Hybrid PTO cycles should be available in combination with the most representative drive cycle for either refuse or utility drive cycles.

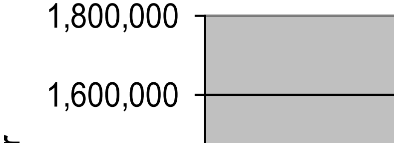
Transmission Spec'ing for Fuel Economy

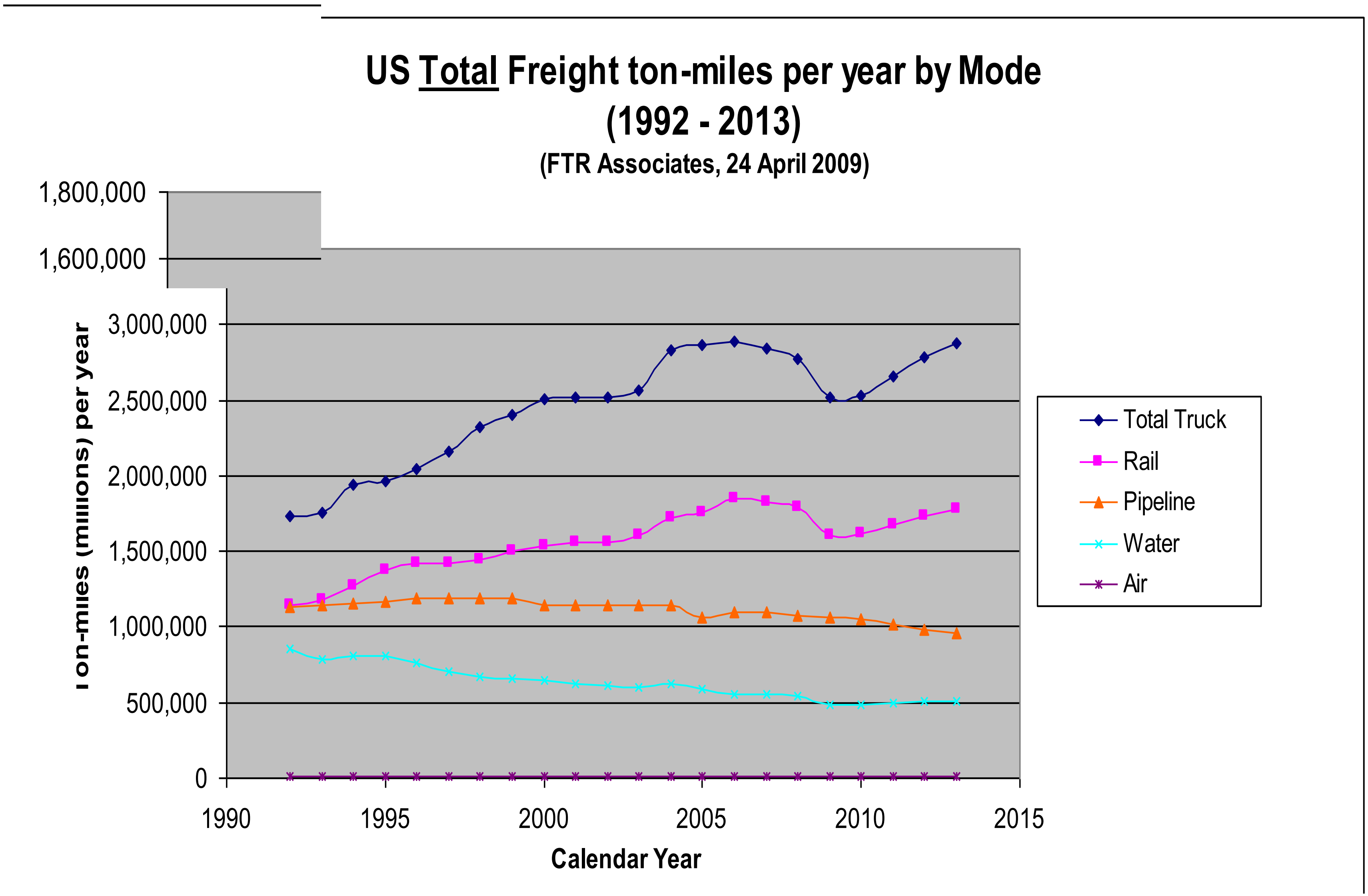
Automatic Transmission Spec'ing Approach

- General perception of Truck Use
  - Highway speed majority of time
  - "Line Haul" type applications
  - Average speed is typically tied to highway speed
  - General outlook is time spent at 55+ MPH
    - Often concerned with a "top speed" when spec'ing driveline
- Based on years of data logs of a variety of in-service duty cycles
  - Data suggests majority of operational time is spent at far less MPH than thought



Allison Transmission
DRIVING TRANSMISSION TECHNOLOGY™


1,800,000
1,600,000


US Total Freight ton-miles per year by Mode
(1992 - 2013)
(FTR Associates, 24 April 2009)
1,800,000
1,600,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Ton-miles (millions) per year
1990
1995
2000
2005
2010
2015
Calendar Year
Total Truck
Rail
Pipeline
Water
Air

Freight Trends are Significant to Transmission Selection

- Many like to think in terms of "steady state"
  - Cruising at highway speeds
  - Average speed is associated with cruise speed

BUT

- With more ton/miles in short and medium haul
  - There is much more stop & go, which translates into more:
    - Shifting
    - Acceleration & Deceleration
  - Acceleration is critical to
    - Average speed (miles per day)
    - Productivity
    - Fuel efficiency

Transmission Spec Decisions

- The transmission must be considered to be part of the vehicle system.
  - Engine
  - Vehicle application
  - Drive cycle
  - Startability requirements
  - Highway cruise speed
  - Top Gear Speed
  - Durability
  - Tires (size and rolling resistance)
- Vehicle system requirements drive the transmission and axle ratio selection
  - Torque Converter (for automatics)
  - Ratio coverage
  - Shift schedule
  - Axle ratio

The transmission spec has significant influence on relative fuel economy/efficiency performance

- Simulation study done to show relative influence of spec decisions

Common specifications:

- Straight truck-On-Highway
- Cummins 2010 ISC 300 hp/860 lb ft
- Allison 3000 HS 6-speed automatic transmission
- 6 x 4 drive configuration
- 500 rev/mile tires (standard radials)
- Smooth concrete road surface
- 96 square feet frontal area
- 0.700 aero drag coefficient

Variation in specs:

- Axle Ratios 4.63 4.88 5.29 5.86 6.14 6.43
- Torque converters: 7 different ones available w. 3000HS
- Shift Schedules: 7 different ones (more are available)

Axle Ratio has the Largest Impact on Fuel Economy

- **Going from a 6.43 to 4.63 axle ratio meets performance requirements and results in a 19% increase in MPG at 55 MPH cruise.**
- **Cruise is completely insensitive to shift calibration and torque converter.**

Torque Converter

- TC418 and TC419 are the only two (of seven) TCs to match the engine
  - Input torque
  - Smoke control
  - Turbo lag
- By holding all variables common except the torque converter running the ARB transient cycle, the fuel economy range is 4.6%

Shift Schedule Considerations

- **Many shift schedules are available and are selected based on engine performance and vocational requirements.**
- **Load Based Shift Schedule (LBSS)**
  - **Combines Performance/Economy when loaded/unloaded**
  - **Optimize shift schedules to align with engine sweet spot**
  - **Impact will be more apparent in real-world operation than a fixed cycle**

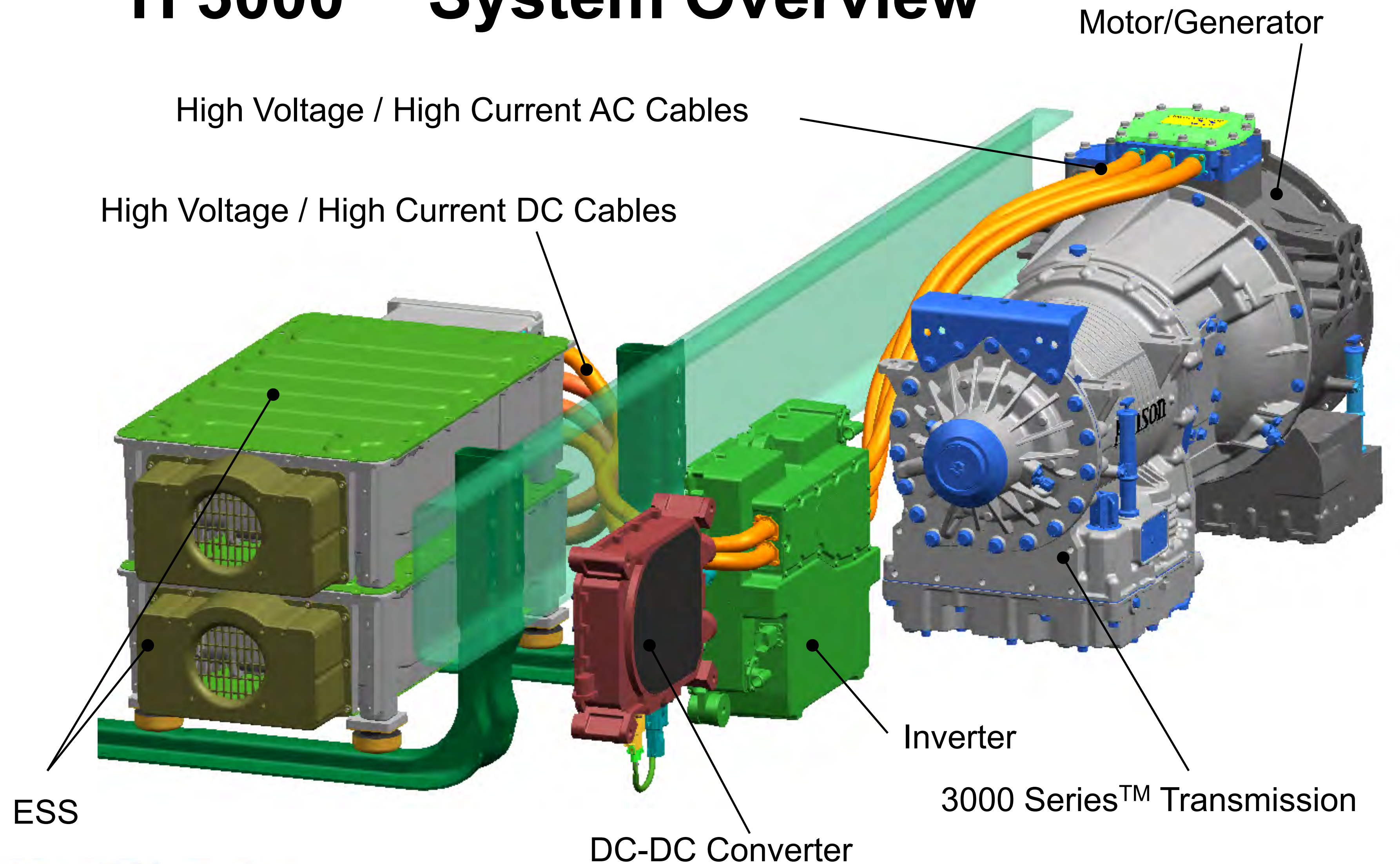
Simulation Conclusions

- Drive cycle is the most important factor in spec'ing a transmission for fuel economy
- Axle ratio has the largest impact on spec'ing an automatic transmission for fuel economy
- Torque converter selection must be matched to the engine
- Shift schedule can be optimized to balance vehicle performance and fuel economy
- Vehicle weight impacts actual fuel economy

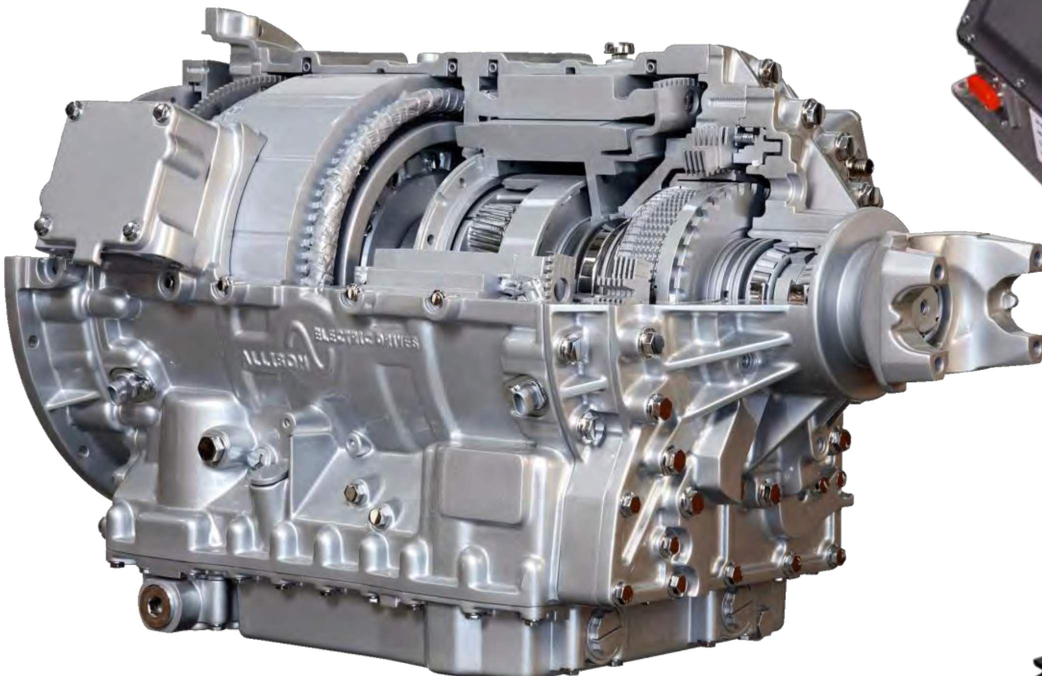
Overview of Allison Transmission's New Technology for Commercial Trucks – H 3000™ Hybrid System

- Demonstration vehicle built
- Used for promotional activities

H 3000™ System Overview



H 40/50 EP™ **Bus Hybrid System**



Allison Transmission
DRIVING TRANSMISSION TECHNOLOGY™

Current H 40/50 EP™ Applications North America

Allison Transmission. DRIVING TRANSMISSION TECHNOLOGY™

Allison Hybrids in Buses Worldwide

Models: H 40/50 EP 2-Mode Hybrids

Buses Delivered Worldwide with H 40/50 EP Hybrids	**4206**	(4022 NAFTA)
Cities Worldwide with H 40/50 EP Hybrid Buses	**189**	(167 NAFTA)
States in United States with H 40/50 EP Hybrid Buses	**39 of 50**	
Countries Worldwide	**9**	
World's Largest Producer of HD Transit Hybrids	**YES**	
Offered by all North American bus manufacturers	**YES**	
Total Accumulated Miles	**> 323,030,875**	
Total Accumulated Kilometers	**> 519,853,587**	
Achieved 100,000,000 Fleet Miles without any "End-of-Life" Hybrid Battery Failures (Since SOP of H 40/50 EPs in October 2003	**YES**	
Gallons Fuel Saved*	**> 17,171,076**	
Liters Fuel Saved*	**> 64,992,524**	
Metric Tons CO2 Eliminated*	**> 169,930**	

Data updated April 22, 2011 / * Indicates Estimated Savings

(i) EPA and NHTSA have not precisely specified what the agencies will consider to be a "complete hybrid system." For example, the Draft RIA appears to indicate that pre-transmission systems constitute such a "complete hybrid system."[67] yet there is not an accepted industry view of this term or what does and does not constitute a complete system. Transmissions are integral to many hybrids and hybrid vehicle systems and cannot be arbitrarily excluded.

(ii) EPA and NHTSA propose different testing systems for hybrid vehicles: testing of a complete vehicle and "powertrain test cell" testing without adequate explanation or justification for this proposal.[68] On what informational basis is this proposal made and would the use of such differential testing protocols be decided by EPA, NHTSA or those manufacturers seeking to test hybrid systems?

(iii) It is unclear as to how the proposed testing protocols for hybrids will account for expected aging of the systems and how such expected aging would affect the end crediting of the hybrid system.

(iv) EPA and NHTSA must give greater consideration to the baseline configuration of hybrids in “A to B” testing. Within both the preamble and the draft RIA, it is not clear as to whether the agencies will require that the baseline vehicle be of the same model year and configuration as normally specified by vehicle purchasers and supplied by equipment manufacturers.

v) The “value” of hybrids relative to conventional vehicles can only be assessed with respect to a real world non-hybrid vehicle of substantially similar type. Given that the transmission/rear axle combination determines the engine torque/speed map for a brake power cycle, EPA should specify how “pre transmission” drivetrain components will taken into account in the intended testing protocol.

(vi) It is unclear as to whether hybrid manufacturers are to submit A vs. B test cycles for each vehicle or a family of hybrid vehicles, or whether some other methodology is intended in the proposed rules.

(vii) It is unclear how accessory/hotel loads will be specified or considered in the A vs. B testing.

(viii) It is unclear whether the test methods are focused specifically on sandwich hybrid and engine hybrid configurations and/or whether the test methods would be limited to such a configurapower take-off tion.

(iv) Engine certifications have traditionally involved criteria pollutant standards. Since the proposed rules address FE and GHG standards, in the case of A vs. B hybrid testing, will criteria pollutants be considered with respect to the certification of a hybrid system or considered separately with respect to engine certification?

(x) It is unclear how EPA and NHTSA contemplate that hybrid vehicles will be certified and by whom. The proposed regulations generally provide that engine manufacturers must comply with Subpart A regulations Subpart G regulations, however, refer not only to engine and vehicle manufacturers but "all other persons." Given the non-engine components that are necessary for the testing, EPA needs to clarify whether a certification can be required from or held by an engine manufacturer, an OEM or a hybrid component manufacturer.

Weighting of Drive Cycles

Drive Cycle Weighting

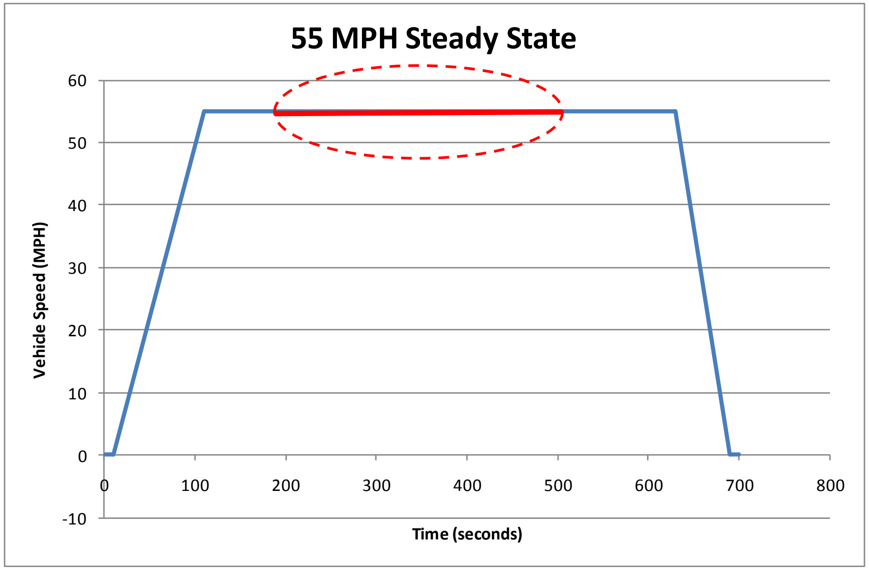
- **Current EPA weighting proposals tend to:**
  - **<u>Over</u>-represent steady-state highway cruising**
  - **<u>Under</u>-represent transient operation (i.e., stop & go traffic, uphill & downhill)**
  - **Underestimate Hybrid benefits**

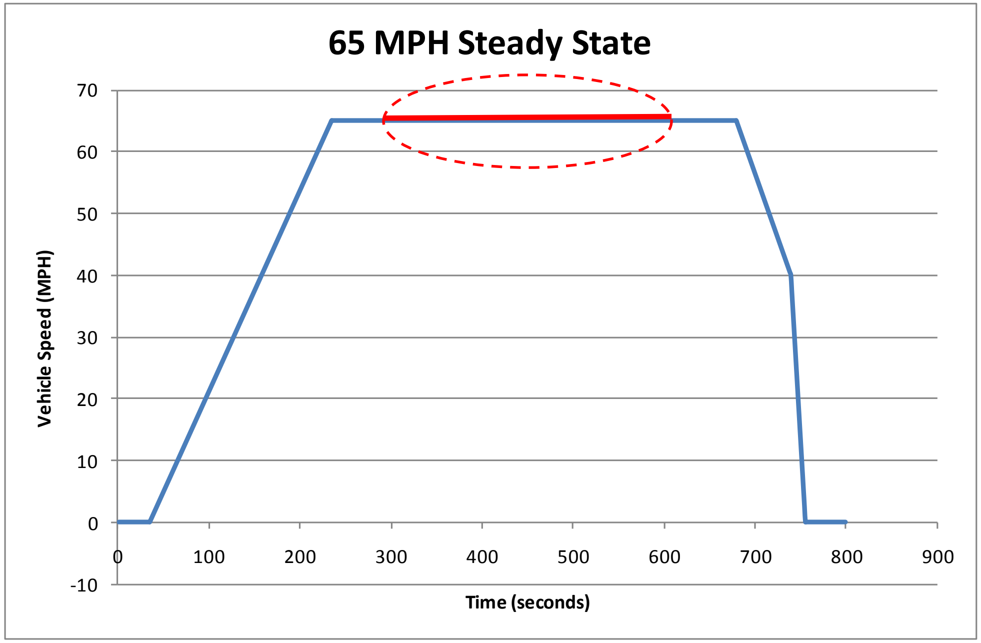
Goal of <u>any</u> hybrid is to exploit vehicle transients:

- **Capture vehicle <u>kinetic</u> energy ($\frac{1}{2}mv^2$) during braking**
- **Capture vehicle <u>potential</u> energy (mgh) during downhill**
- **Re-use the energy for propulsion**

Common Highway Cruise Cycles

GEM: 55 mph & 65 mph Cruise Cycles





A-to-B Testing: 55 mph & 65 mph Cruise Cycles

300 seconds @ 55 mph and 65 mph (+/- 1.0 mph)

Common Highway Cruise Cycles

In order to be able to

- **Maintain commonality between testing and simulation**
  - **drive cycles**
  - **weighting percentages**
- **Avoid confusion among like-named cycles**

Allison recommends using the same cycles in GEM and A-to-B testing to represent cruise.

Weighting by Time (not distance)

Current EPA Proposal:

- **3 basic sub-cycles: Transient, 55 mph Cruise, 65 mph Cruise**
- **All vehicles will be tested on same 3 basic sub-cycles**
- **Differences in overall drive cycle according to vehicle operation to be accommodated by mathematical "weighting" of each sub-cycle**

Allison Comment:

- **This approach is reasonable in principle**
- **Seeks to comprehend a broad variation in actual vehicle operation without placing a huge burden of test/simulation on OEMs**

However, there are some areas of confusion…

Weighting by Time (not distance)

Table 1 to § 1037.510—Weighting Factors for Duty Cycles

	Transient	55 mph Cruise	65 mph Cruise	PTO
Vocational	42%	21%	37%	0%
Vocational, with PTO	30%	15%	27%	28%
Day Cabs	19%	17%	64%	0%
Sleeper Cabs	5%	9%	86%	0%

Issue: Are the % weightings based on time or distance?

- **PTO operation in "Vocational, with PTO" must be time based (PTO operates with vehicle standing still)**
- **Other weightings in the table may be distance based**
- **The RIA uses conflicting terminology in the same sentence (page 3-25): "… the line haul trucks spent 5% of the miles at speeds less than 50 mph, 17% between 50 and 60 mph, and 78% of the time at speeds greater than 60 mph".**

Weighting by Time (not distance)

Allison Recommendations:

- **Always use "% weighting" based upon time**
- **Make time-weighting very clear in the regulations**

Reasoning:

- **To avoid confusion, either time or distance must be used**
- **If stationary PTO is involved, time must be used**
- **Time-based weighting is very common in the industry**
- **Time-based weightings can reflect the same distance-based prescription**

Weighting of Current Vehicle Types

General Trends:

- EPA 2010 weightings (vs. EPA 2007 Draft Protocol) show:
  - less transient operation
  - more operation > 60 mph
  - higher average speed

- Allison weightings (vs. EPA 2010) reflect
  - more transient operation
  - less operation > 60 mph
  - lower average speed
  - operation on grades

Note: Allison measured & analyzed 185 in-service drive cycles:

- - 6 Sleeper Cab
- - 21 Day Cab
- - 158 Vocational

Weighting of Current Vehicle Types

Sleeper Cabs

	SLEEPER CABS				
Duty Cycle	2007 EPA		2010 EPA	Allison Data	
	% Time	% Distance	% Distance	% Time	% Distance
Transient (<50 MPH)	55.2%	8.9%	5%	24.1%	6.7%
50 MPH - 60 MPH	10.1%	4.2%	9%	14.7%	15.6%
>60 MPH	34.7%	86.9%	86%	61.2%	77.7%
Avg MPH	60.2		61.6	56.8	

Notes:

- **EPA 2007 data included speed vs. time traces, so % time was available**
- **% time ratings can be adjusted to accord with a % distance rating**
- **Allison data includes grades**

Weighting of Current Vehicle Types

Day Cabs

	DAY CABS				
Duty Cycle	**2007 EPA**		**2010 EPA**	**Allison Data**	
	% Time	**% Distance**	**% Distance**	**% Time**	**% Distance**
Transient (<50 MPH)	**41.7%**	**19.6%**	**19%**	**61.3%**	**23.2%**
50 MPH - 60 MPH	**35.6%**	**47.5%**	**17%**	**12.1%**	**22.8%**
>60 MPH	**22.7%**	**32.9%**	**64%**	**26.6%**	**54.0%**
Avg MPH	**50.5**		**53.9**	**33.8**	

Notes:
- **Strong disparity in weighting & average speeds between EPA & Allison**
- **Allison data includes grades**

Weighting of Current Vehicle Types

Vocational Vehicles

	VOCATIONAL VEHICLES				
Duty Cycle	2007 EPA		2010 EPA	Allison Data	
	% Time	% Distance	% Distance	% Time	% Distance
Transient (<50 MPH)	87.5%	66.6%	42%	83.1%	65.8%
50 MPH - 60 MPH	12.5%	33.4%	21%	6.5%	13.8%
>60 MPH	0.0%	0.0%	37%	10.3%	20.4%
Avg MPH	28.6		42.0	18.1	

Allison Data for Vocational Vehicles summary includes all data from duty cycles that are included in the EPA's definition of Vocational Vehicles - Refuse, Dump, Mixer, Transit, School Bus, P&D, etc.

- **EPA 2007 was somewhat close to the Allison Data**
- **But EPA 2010 shows an enormous disparity, shift from EPA 2007**
- **Allison data includes grades**

Weighting of Vocational Sub-Groups

General:

- Current EPA proposal uses 1 weighting for all Vocational vehicles
  - Actual cycles vary significantly among Vocational sub-groups
  - Establishing a few sub-groups may be helpful
  - Could accommodate vocations which lend themselves to hybrids
- EPA's suggested vocational sub-groups:
  - Urban (City Bus)
  - Mixed Urban/Freeway (P&D, delivery)
  - Refuse Packer
  - Utility Truck with Boom

Weighting of Vocational Sub-Groups

Vocational vehicles per EPA definition

Allison Experience Base

	Transient (<50 MPH)		50 MPH - 60 MPH		>60 MPH		Count	Vehicle Class
VOCATIONAL VEHICLES	% Time	% Distance	% Time	% Distance	% Time	% Distance		
EPA Defined Vocational - Allison Data	***83.1%***	***65.8%***	***6.5%***	***13.8%***	***10.3%***	***20.4%***	***158***	
Oil Field, Dual Mode, Straight Truck	68.3%	60.0%	12.3%	16.1%	19.3%	23.9%	5	8
Refuse, Front Loader, Straight Truck	92.2%	78.9%	7.5%	20.1%	0.4%	1.0%	11	8
Refuse, Rear Loader, Straight Truck	91.7%	75.5%	6.2%	17.9%	2.1%	6.6%	16	8
Refuse, Recycling Roll Off, Straight Truck	86.2%	63.6%	7.9%	20.2%	5.9%	16.3%	1	8
Refuse, Side Loader, Straight Truck	99.1%	96.5%	0.9%	3.5%	0.0%	0.0%	2	8
Dock Spotter, Tractor Trailer	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	3	8
Concrete Mixer, Front Discharge, Straight Truck	80.9%	67.0%	10.9%	24.5%	8.2%	8.5%	14	8
Construction, Dump Truck, Straight Truck	89.0%	70.0%	8.1%	21.2%	2.9%	8.9%	4	8
Equipment Hauler, Tractor Trailer	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	2	8
Transit, Articulated Bus	99.4%	97.4%	0.4%	1.6%	0.2%	1.1%	5	8
Transit, 40 Foot Bus	98.0%	93.7%	1.5%	2.0%	0.5%	4.3%	32	7
Shuttle Bus	91.2%	71.7%	5.3%	16.0%	3.5%	12.3%	8	6
Intercity Transit Coach	86.8%	81.9%	10.8%	8.8%	2.4%	9.3%	4	8
Tour Coach	18.1%	10.7%	14.8%	14.8%	67.2%	74.5%	7	8
School Bus	93.3%	87.6%	6.4%	12.2%	0.3%	0.2%	8	5
Beverage Delivery, Straight Truck	87.6%	73.2%	8.2%	17.5%	4.1%	9.3%	2	5/6
Beverage Delivery, Tractor Trailer	81.9%	63.7%	7.5%	13.3%	10.6%	23.0%	4	6/7
City Delivery, Straight Truck	69.6%	58.0%	8.1%	17.8%	22.3%	24.2%	11	5/6
City Delivery, Walk-In Van	84.5%	60.9%	6.1%	17.2%	9.4%	22.0%	19	4/5

Allison data includes grades

Weighting of Vocational Sub-Groups

Summary of Allison Recommendations

	Transient (<50 MPH)		50 MPH - 60 MPH		>60 MPH		Count	Vehicle Class
	% Time	% Distance	% Time	% Distance	% Time	% Distance		
Urban	98.0%	93.7%	1.5%	2.0%	0.5%	4.3%	32	7
Mixed Urban	69.6%	58.0%	8.1%	17.8%	22.3%	24.2%	11	5/6
➡ Refuse Packer	92.2%	78.9%	7.5%	20.1%	0.4%	1.0%	11	8
➡ Utility Truck	69.6%	58.0%	8.1%	17.8%	22.3%	24.2%	11	5/6

➡ **Refuse & Utility do not break out PTO operation separately**

The separate Vocational Sub-Groups are justified:

- **Large variation between cycles, even in propulsion mode alone**
- **PTO loadings in Refuse and Utility add to the variation**

Accounting for Road Gradients

Situation

- Allison cycle data reflect grades
- EPA cycles may not
- Grades are a part of real-life operations
- Grades are well-suited to capture hybrid advantages

Allison General Suggestion

- Either include grades in the cycles
  (Can typical dynamometers/test stands accommodate them?)
  (Uphill means just added load, downhill means a "powering" dyno)

- Or increase the "% transient" time when weighting all cycles

Accounting for Road Gradients

Complications

- Allison cycle data does not include measured grade data
- Difficult to measure until recently (even GPS is not accurate)
- Broad variation in grades across the USA
- So, how can grades be quantified?
  (either directly or in additional % transient time)

Allison Specific Suggestions

Allison can only show that road gradient is highly significant:

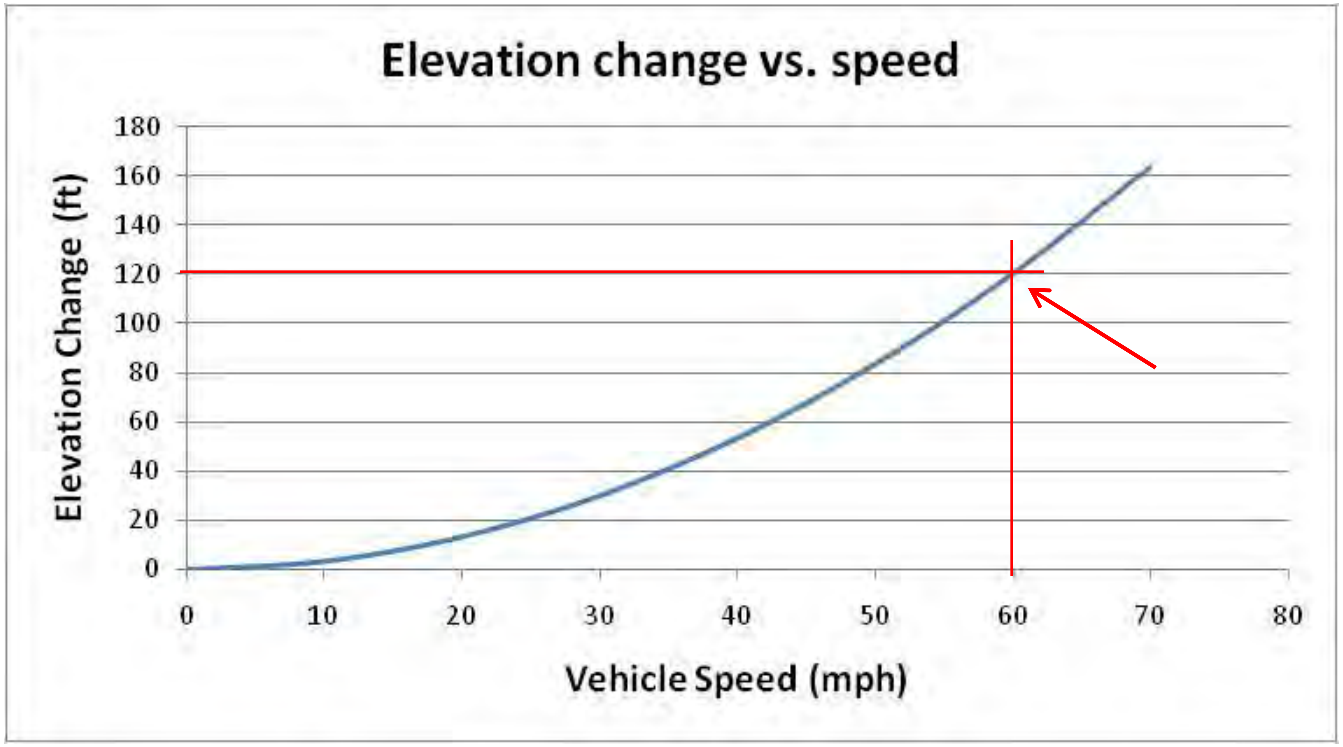
- **Importance of an Inclinometer:**
  - Allison's next generation controls will include an inclinometer
  - Competitive automated transmissions also use an inclinometer

- **Show quantitative relationship between grade and vehicle speed:**
  - Important to hybrid operation
  - Compares Energy from grade to energy from vehicle speed

Accounting for Road Gradients

Grade Elevation vs. Vehicle Speed

Kinetic Energy = $\frac{1}{2}mv^2$
Grade Energy = mgh → **$mgh = \frac{1}{2}mv^2$** → **$h = \frac{v^2}{2g}$**



Example: Stop from 60 mph involves the same energy as a drop of 120 feet.
(less than a half-mile on a 5% grade)

Allison Test Experience and Lessons Learned

Allison Test Experience and Lessons Learned

- Purpose of this discussion:
  - Identify & communicate key Fuel Economy Test Factors
    - Identify differences between engine test cell & vehicle roll dyne testing
  - Discuss key fuel economy testing measures
  - Discuss lessons & observations from initial EPA testing with Allison's 2000 Series™ transmission

Allison Test Experience and Lessons Learned

- Test Factors influencing Fuel Economy & differences between these factors in engine test cells & vehicle roll dynes
  - Engine test factors
  - Transmission test factors
  - Environmental, Duty Cycle & Use factors
  - Vehicle factors
  - Test methodology, accuracy & repeatability factors

Test Factors influencing Fuel Economy & differences between these factors in engine test cells & vehicle rolls dynes (Engine Factors)

Test factors influencing fuel economy	Level of engine test cell to vehicle roll dyne difference	Level of difficulty to eliminate or reduce difference between engine test cell & vehicle roll dyne testing
Engine Torque curve (various pedal positions)	No difference with same Engine Cal	
Idle Speed	No difference with same Engine Cal	
Maximum (governed) speed	No difference with same Engine Cal	
Brake Specific Fuel Consumption Curve	No difference with same Engine Cal	Recent EPA / ATI fuel economy test results indicate a difference in fuel maps even though engines were intended to be the same
Throttle to Torque Relationship Curves (pedal progression)	No difference with same Engine Cal	
Turbocharger / Smoke Control Lag Characteristics	No difference with same Engine Cal	
Accessory Losses as a function of engine speed	Test cells may not have fans or alternators & typically do not run compressors or AC	Significant impact if these differences must be eliminated
Engine Inertia	No difference if engine is the same	
Fuel type, density & temperature	No difference if these factors are controlled	Equipment & facilities to control these factors is expensive & not common

No or small difference	Some difference	Significant difference

Test Factors influencing Fuel Economy & differences between these factors in engine test cells & vehicle rolls dynes (Transmission Factors)

Test factors influencing fuel economy	Level of engine test cell to vehicle roll dyne difference	Level of difficulty to eliminate or reduce difference between engine test cell & vehicle roll dyne testing
Transmission mechanical factors	No difference if the same configuration transmission is used for engine test cell or vehicle roll dyne testing **(see note 1)**	
Model		
Gear ratios		
Torque converter		
Spin losses		
Pump losses		
(Gear) Range inertia		
Transmission control capabilities	No difference if the same transmission calibration is used for engine test cell or vehicle roll dyne testing **(see note 1)**	
automatic load based shift pattern selection		
Automatic shift to neutral when stopped		
Optimized shift pattern		
Rate of acceleration management		

Note 1: changes in test duty cycle may require changes in transmission mechanical & controls configuration

No or small difference	Some difference	Significant difference

Test Factors influencing Fuel Economy & differences between these factors in engine test cells & vehicle rolls dynes (Environmental, Duty Cycles & Use Factors)

Test factors influencing fuel economy	Level of engine test cell to vehicle roll dyne difference	Level of difficulty to eliminate or reduce difference between engine test cell & vehicle roll dyne testing
Ambient temperature	Both test cells & vehicle roll dynes require environmental test capability to control these factors **(see note 1)**	
Hot & cold temperature extremes		
Humidity & air density		
Terrain; flat, hilly, mountains etc	Both test cells & vehicle roll dynes can manage these factors via duty cycle definition **(ref note 2)**	
Road conditions; smooth, bumpy etc		
Driving conditions; congested, city, hi-way etc		
Application; pickup & delivery, construction, garbage, over the road etc		
Driver; passive, aggressive, nervous etc	Drivers in roll dynes will add variation not seen in test cells using automated test cycles	automated drivers in roll dynes needed to eliminate variation
Reasonable duty cycles & use of accelerator pedal & brake	Test cells with automated cycles can make unrealistic accelerator pedal & brake commands	Assure all duty cycles are representative of typical vehicle use & are not too slow, too abrupt or too transient.

Note 1: Environmental test cells for BIG trucks are very expensive & very uncommon

Note 2: Different duty cycles require different transmission & vehicle configurations

No or small difference	Some difference	Significant difference

Test Factors influencing Fuel Economy & differences between these factors in engine test cells & vehicle rolls dynes (Vehicle Factors)

Test factors influencing fuel economy	Level of engine test cell to vehicle roll dyne difference	Level of difficulty to eliminate or reduce the difference between engine test cell & vehicle roll dyne testing
Vehicle mass Vehicle rolling resistance Vehicle aerodynamic drag Number, age & design of tires Axle ratio	Differences in these factors are a function of differences between engine test cell & roll dyne control & measurement equipment.	The level of difficulty to reduce or eliminate these differences is a function of the test cell changes / equipment needed to obtain accurate FE test results

No or small difference	Some difference	Significant difference

Note 1: The EPA agreed to change the axle in initial testing with the ATI 2000 Series™ transmission. This change was appreciated & necessary for the 2000 Series™ transmission to demonstrate representative FE test results

Note 2: test cells able to perform high accuracy fuel economy & emissions testing on complete powertrain systems are rare & expensive

Test Factors influencing Fuel Economy & differences between these factors in engine test cells & vehicle rolls dynes (Test methodology, accuracy & repeatability)

Test factors influencing fuel economy	Level of engine test cell to vehicle roll dyne difference	Level of difficulty to eliminate or reduce the difference between engine test cell & vehicle roll dyne testing
First time test accuracy	Both engine test cells & vehicle roll dynes are subject to these test Quality & methodology factors.	Test methodology will need to include "sanity" checks, use of test "masters" should be considered & comparison of test results to prior data may not be possible. (in other words, all tests may need to include a new baseline)
Time to time variation in test results (for example: tests are run months apart)		
Part to part variation (for example: a transmission or engine is changed / updated		
Test cell equipment change variation (for example: a dyne or torque meter is changed)		
Test cell to test cell variation (for example: differences between the EPAs & ATIs test cell)		

Note: During initial EPA testing with the ATI 2000 Series^{TM} transmission, an EPA torque measurement problem was identified via a "sanity" check.

No or small difference	Some difference	Significant difference

Testing accuracy, repeatability & the price of the last 1% – 2%

Indy cars are rare & very expensive to buy & operate:

- The price of a race track ready Indy Car is over $500k.
- The price to operate an Indy Car for a whole race season varies between $4M & $8M per year

- For $4M you can run an Indy Car that will perform within 2% of the best car on the track.
  - The problem is in Indy Car racing the difference between first & last is 2% or less.
  - For $8M & the associated process, equipment & labor, you can get the last 2% & compete to win.

- To draw from Indy Cars & apply these lessons to commercial vehicle FE testing:
  - The equipment needed to test FE accurately is rare & expensive
  - The differences between test configurations is small in many cases, 1% - 2%
  - The test equipment & process must be capable to “find” these small percentages &, like Indy Cars, finding the last couple percent is expensive & takes special process & equipment.

Summary of test factor observations:

- The “same” is not always the “same”

- Several test factors are important & test methodology must allow key factors to be optimized
    - Changes in test duty cycle may require changes in transmission mechanical & controls configuration and / or changes in the vehicle
    - Defining several “core” powertrains & duty cycles is a possibility, however, optimization with several FE factors is necessary to assure representative results (ref: EPA allowing ATI’s request to change the axle ratio used in initial testing)

- Environmental test capability is needed & is expensive & rare

- To assure FE testing accuracy & repeatability test practices will need to include “sanity” checks. Due to time to time & other sources of test variation test “masters” should be considered & comparing test results with prior data may not be possible. New “baseline” testing may be required for all tests.

- A lot of test factors are important. There’s a lot to learn & evolve with test methodology, process & facilities. There will likely be a shortage of test facilities able to provide accurate & repeatable test results. The importance of reducing our environmental risks is extreme.

Considering these facts, …………………. What to do?

Considering these facts, ………………….. What to do?

This coming week end 40 plus drivers & cars will attempt to qualify for the Indy 500; only 33 of them will make the field. One of those 33 will win the purse of over $2M! (the prize is large!)

To make the field, the participants must post one of top 33 Qualification speeds. Qualifications consists of 4 laps where the drivers hold their breath the entire 4 laps due to the extreme risk.

To Qualify the race cars are set up in a fashion not usable on race day. Gears are removed from the transmissions to reduce drag, radiators are blocked to reduce drag etc. These set ups produce good results for 4 laps; soon afterwards, the cars break down.

With the EPA the heavy truck industry is entering a race. The race is for the long haul, the whole 500 miles & not just 4 laps. The race is to lead the way towards heavy trucks working to improve their environmental friendliness.

Qualification set ups won't get this done. We need race set ups; set ups good for the whole 500 miles.

We do not have race set ups defined yet, but, we clearly must get started; and, we must recognize the need to run the race & not just Qualify. We, just like race cars, need to define the key race tracks (duty cycles) & key vehicle & powertrain factors to improve fuel efficiency. Then, put the car on the track in a few key configurations & learn & evolve the test process with an eye on winning the race rather than just running 4 laps to Qualify.

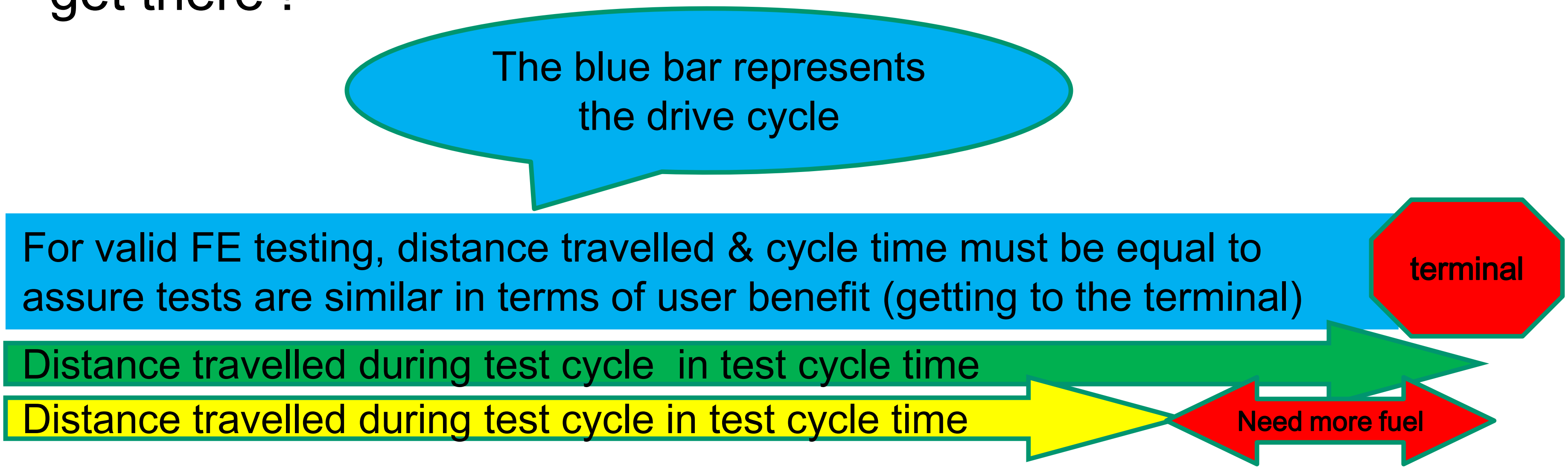
Allison Test Experience and Lessons Learned

- Purpose of this discussion:
  - Identify & communicate key Fuel Economy Test Factors
    - Identify differences between engine test cell & vehicle roll dyne testing
  - **Discuss key fuel economy testing measures**
  - Discuss lessons & observations from initial EPA testing with Allison's 2000 Series™ transmission

Fuel Economy testing measures (used in recent EPA / ATI Fuel Economy testing)

test measures	units	comment
Distance travelled during the test duty cycle	Miles or feet	A component of the traditional measure of fuel economy, MPG. This measure assures test configurations are providing the same user benefit.
cycle time	seconds	used to compare cycle completion time. This measure assures test configurations are performing similarly for users (see slide 91)
vehicle speed	average miles / hour	used to compare vehicle speed over the test cycle. Very low speed cycles are not typical.
fuel used	grams	traditional EPA measures
MPG	miles / gallon	
work, all	(hp hr) (all work)	Use of ALL work is required since all work done with the engine influences fuel use / efficiency
work, positive	(hp hr) (+)	
fuel efficiency	(hp s / g)	All work per grams of fuel used. The is a key measure of fuel use since it reflects work done per unit of fuel.

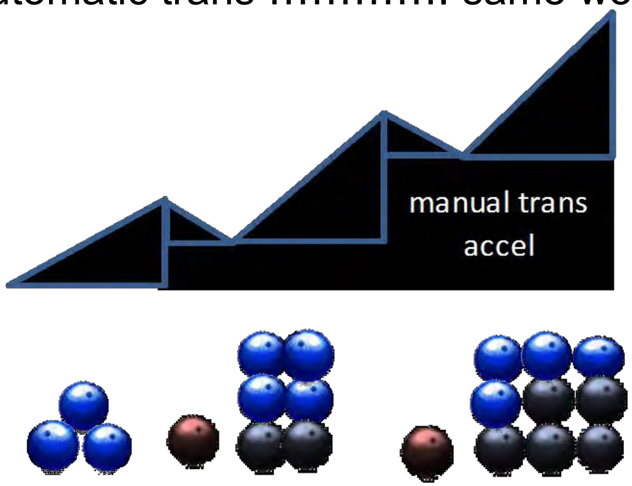
Without measures for distance travelled or cycle time, the vehicle may not get to the terminal or will need more fuel to get there !

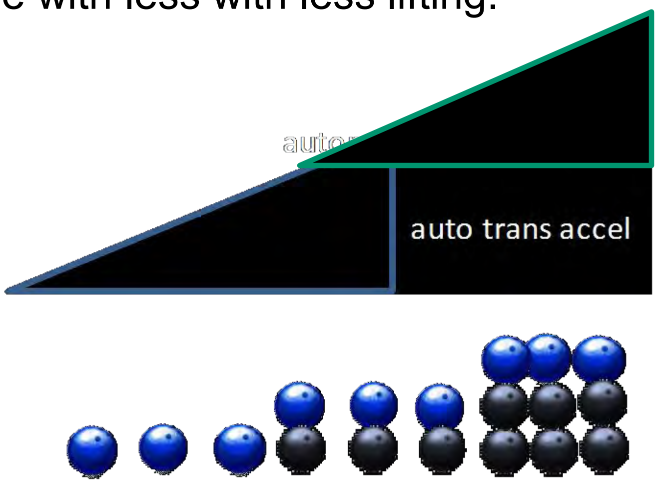


test measures	units	comment
Distance travelled during the test duty cycle	Miles or feet	A component of the traditional measure of fuel economy, MPG. This measure assures test configurations are providing the same user benefit.
cycle time	seconds	used to compare cycle completion time. In ATI's view this is a critical measure to assure test configurations are performing similarly for users

A comparison of automatic & manual transmission acceleration using work done to lift bowling balls as an illustration

- work is represented by lifting bowling balls onto a pile
- This includes re-lifting those bowling balls that fall off the pile during manual trans power interrupts (positive work does not include re-lifting, all work does)
- The automatic trans with power shifts drops no bowling balls & completes the same acceleration lifting fewer bowling balls . This result represents improved fuel efficiency with the automatic trans ………… same work done with less with less lifting.





bowling balls lifted	3		4		4		3	3	3
bowling balls dropped		1		1			0	0	0
total lifts	3		7		11		3	6	9

Summing up measures: The importance of distance travelled, time to cross the finish & fuel efficiency

Indy car racing has very good measures.

- The car crossing the finish with all laps complete in the shortest length of time wins the race

To draw from these measures & apply them to the operation of commercial vehicles:

- Finishing all the laps is important. You cannot just leave the last 3 garbage cans at the end of the shift or fail to drop off the last load of milk! Measuring distance travelled is important!

- Whoever completes the race in the shortest amount of time using no more than the prescribed amount of fuel wins. Whoever finishes the job in the least time in an expensive / revenue generating commercial vehicle can use the vehicle to generate additional revenue. Measuring time to complete jobs is important.

- The amount of fuel Indy cars use in a race is legislated & very limited. Those who burn fuel inefficiently will not win races. Measuring fuel efficiency is important & reflects the meaningful measure of work done per unit of fuel used!

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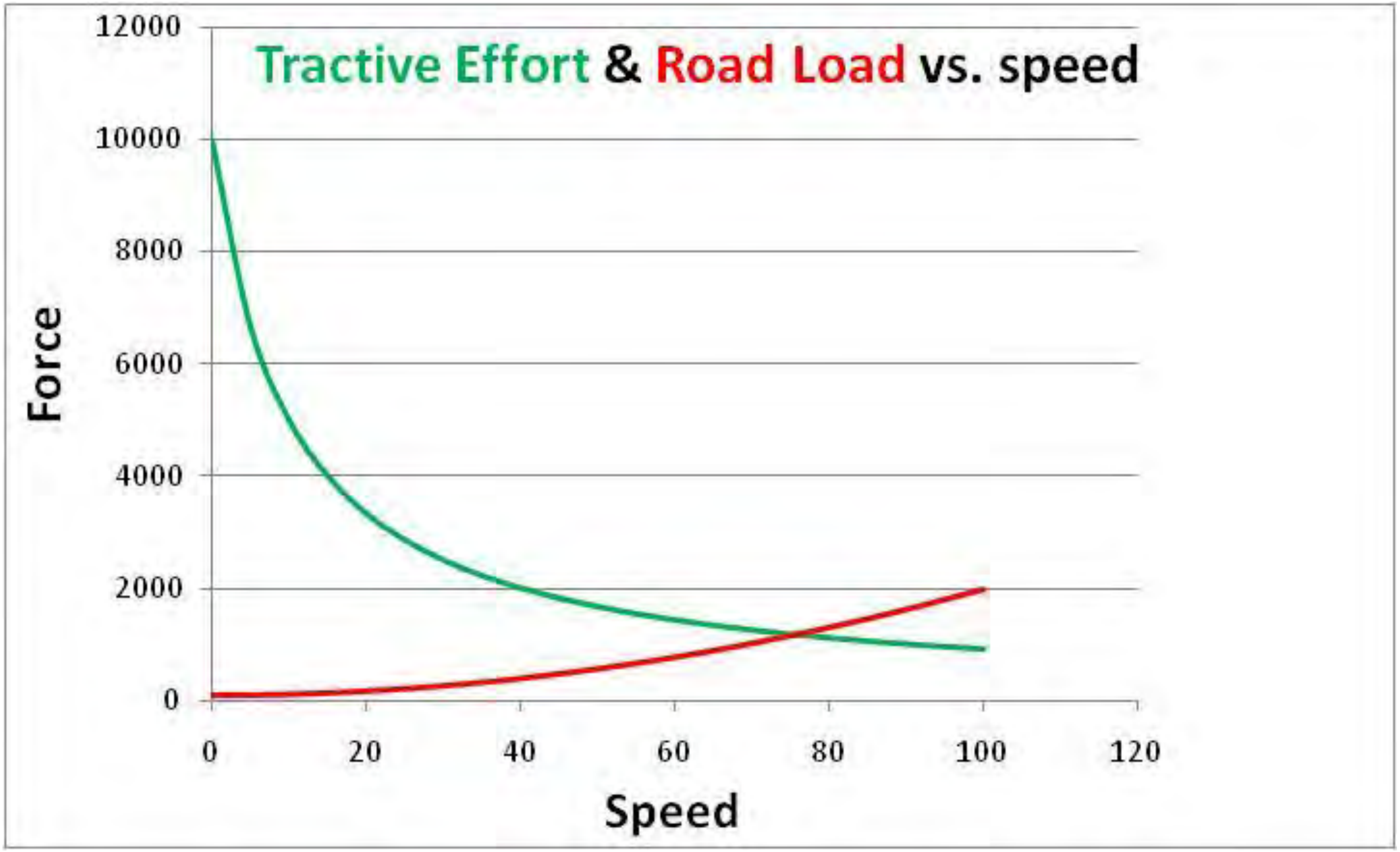
Other lessons learned & observations from initial EPA testing

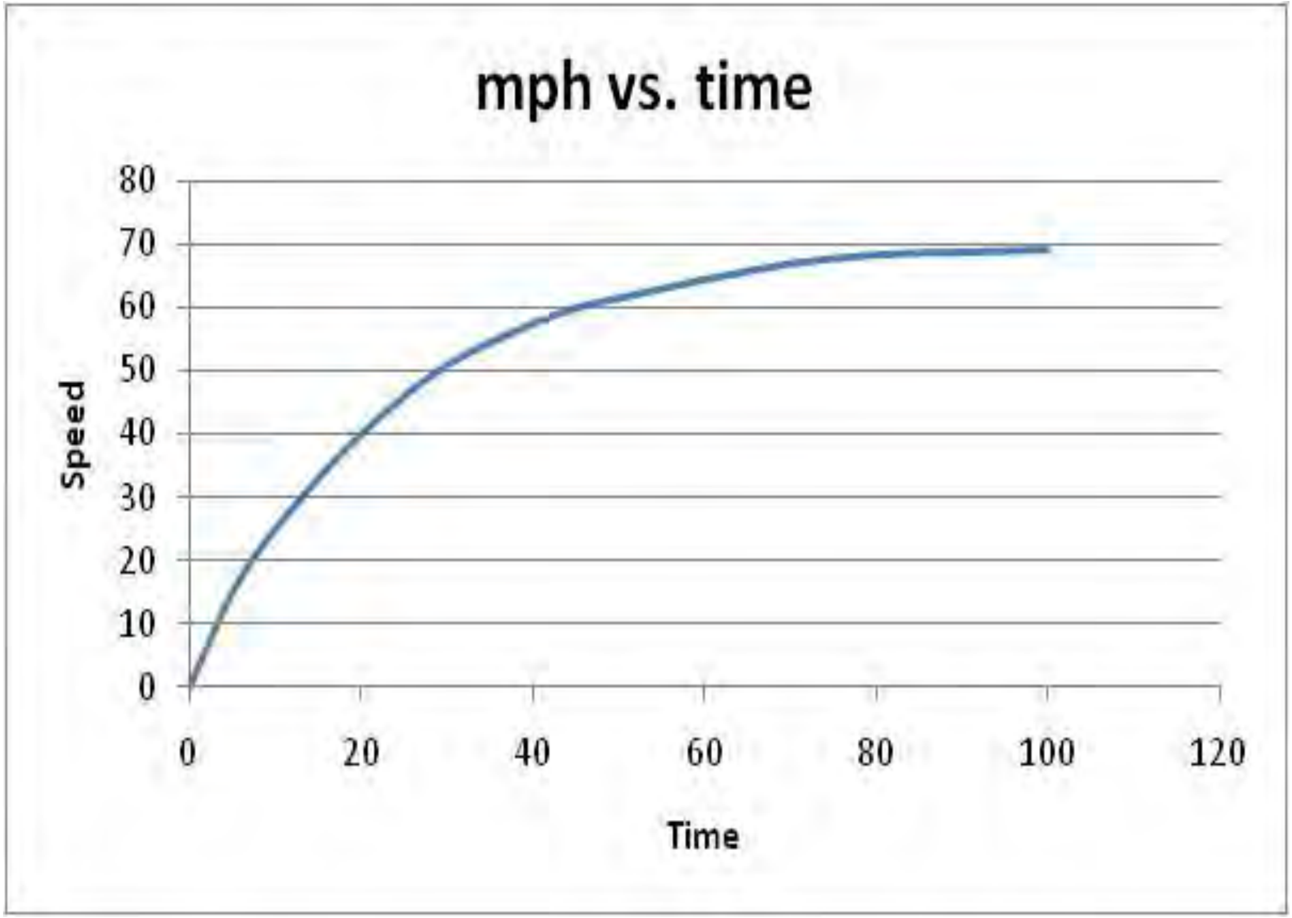
lesson	recommendation
Some Duty cycles are not realistically aggressive	Define test cycles representative of drivers & vehicles in real world use. Assure we do not strive for "one cycle fits all" and, in fact, end up with "one cycle fits none".
Some duty cycles' average speed is not realistic	
Test representative vehicle weights	
Straight Line acceleration is not representative of real world	A more natural diminishing acceleration with a smooth transition to cruising is more realistic and will eliminate some controls issues.
Vehicle model should be the same for all powertrains	The EPAs "coast down" vehicle test disadvantages automatic transmissions since the drive line cannot be de-coupled. Use of a common vehicle model keeps the playing field level.

“Natural” Acceleration

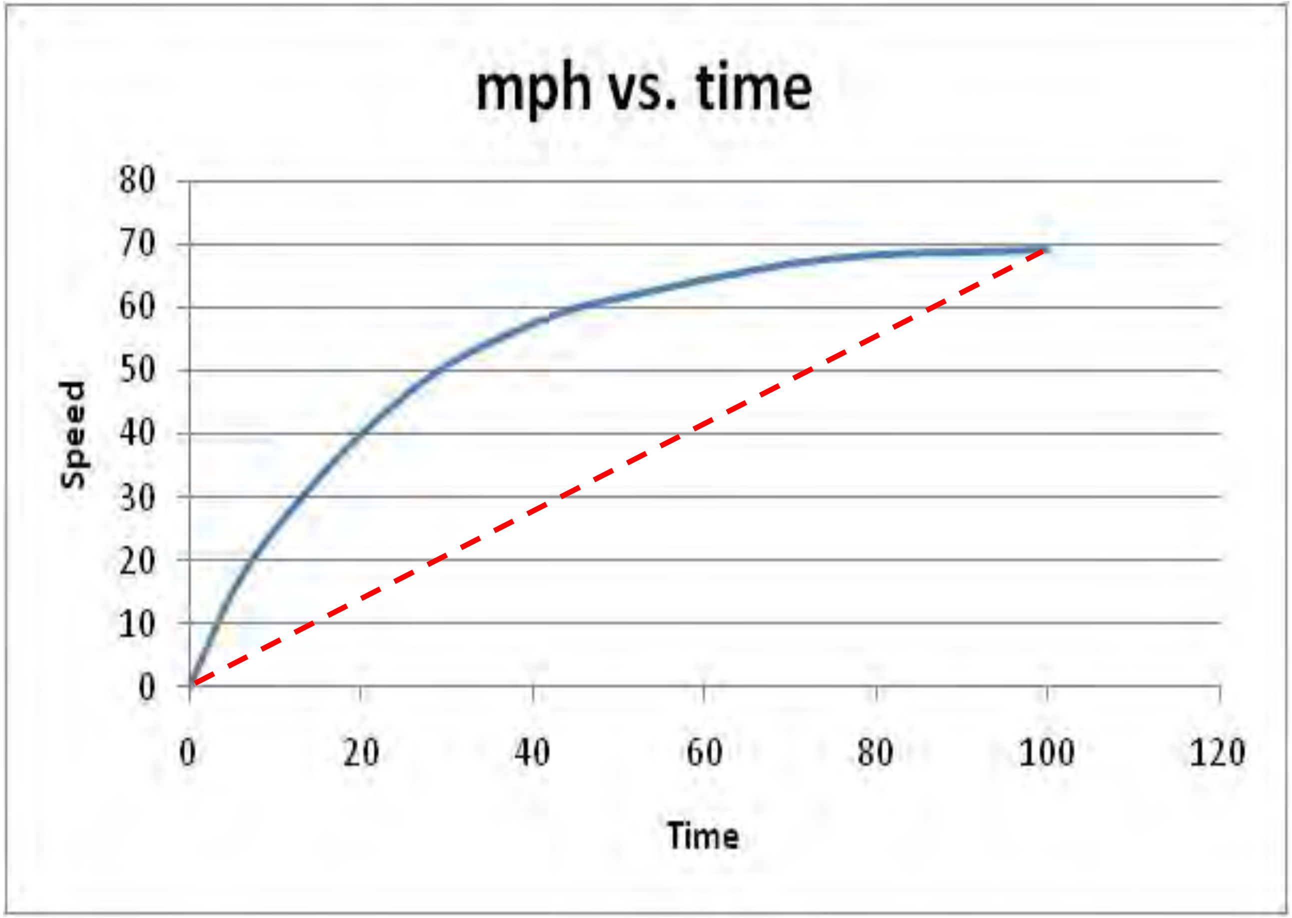


Results in the typical “speed vs. time” graph…

"Natural" Acceleration



“Natural” Acceleration



Straight line acceleration is highly “unnatural”…

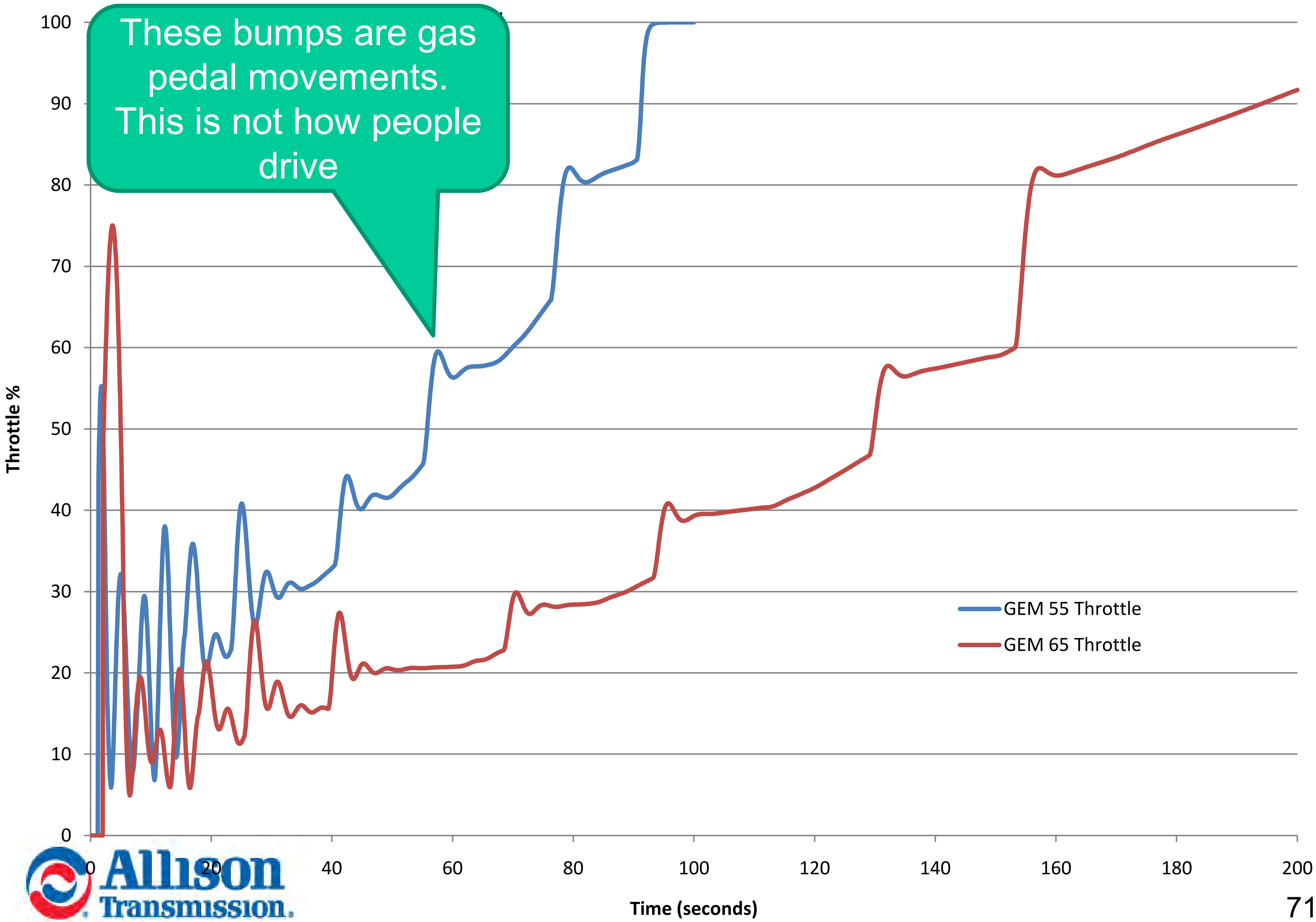
Straight-line Acceleration

- Throttle must be "jockeyed" to try to fit the straight line

- Introduces transient operations which:
  - Are not typical of actual operation
  - Reduce ability to put in vehicle energy efficiently
  - Acceleration rate is very slow

  - Here's what happens with straight line cycles in terms of gas pedal movement
    - keep in mind, this applies to the EPA Transient cycle too

Straight line acceleration throttle pedal movement



Allison Transmission. DRIVING TRANSMISSION TECHNOLOGY™

Standardized on road test (SORT) Process

- SORT is a European standard
- SORT accepts that straight-line acceleration is not realistic
- SORT sets start & end points (i.e, average acceleration); in-between is flexible
- SORT acceleration is far quicker than EPA cycles

Other lessons learned & observations from initial EPA testing

lesson	Recommendation / observation
Time from engine start to start of cycle not closely controlled	The EPA includes an engine start at the beginning of their cycles. There does not seem to be a set time to begin the test cycle. Establish a set time.
For cruise cycle data, the EPA is only using a portion of the cycle where they are at cruise speed	For the 55 mph cruise and 65 mph cruise cycles, the EPA only used the last 300 seconds of steady-state operation & not the entire cycle to get their fuel economy number. This gives MTs an advantage since their power interrupts during acceleration are excluded from the FE measurement.
Powertrain Test Stand Set-up	The EPA's use of an AC motoring dyne, no inertia wheel, and an inline torque meter for dyne control offers several advantages for fuel testing over the ATI test cell set-up of an EC brake, inertia wheel, and load cell for dyne control.
Torque Transducer Specification	Torque transducer selection is key. The EPA has standards to determine the required accuracy of their torque transducer to insure good data. ATI should follow their standards for future testing.
Require that measured torque be within certain limits of requested (vehicle model) torque.	The EPA has requirements that the measured torque be within certain limits of the modeled vehicle torque. This requirement insures that the test cell is accurately modeling the vehicle. This is good test practice.

Allison Test Experience and Lessons Learned

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  - Discuss key fuel economy testing measures
  - Discuss lessons & observations from initial EPA testing with Allison's 2000 Series™ transmission
  - **End of this section of the presentation**

Wrap-up

Closing Remarks

- Allison, as a leader in transmission technology, has made several recommendations based on extensive experience in the medium and heavy duty vehicle market
- Thank you, EPA, for the opportunity to share our views for your consideration and action.