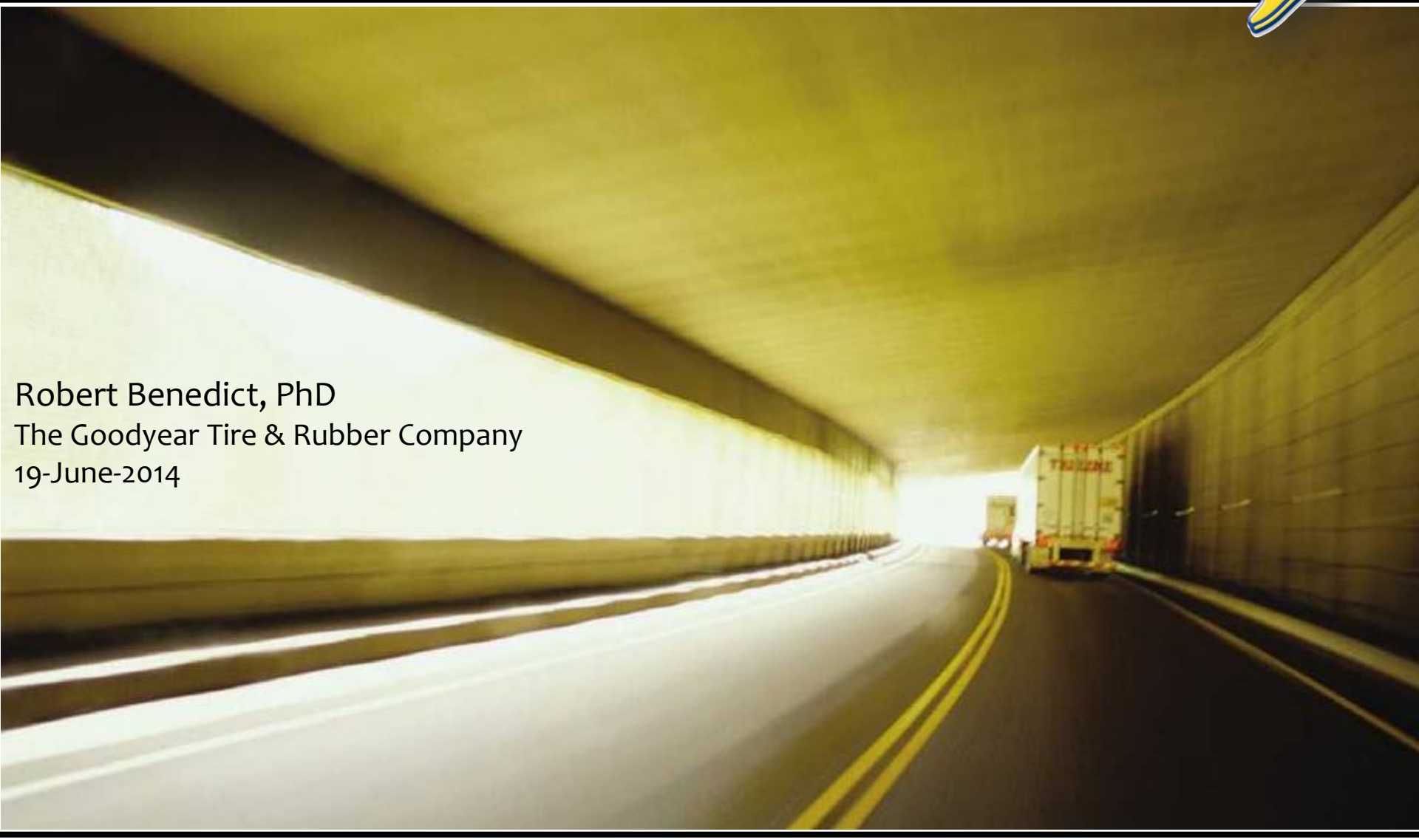
A System for Automatically Maintaining Pressure in a Commercial Truck Tire



Robert Benedict, PhD
The Goodyear Tire & Rubber Company
19-June-2014

Overview

Timeline

Project Start – 01-Oct 2011

Project End – 31-May 2015

Percent Complete – 69% (a)

Phase I: Planning and Initial Design
(06 months) Oct 2011 – Mar 2012

Phase II: Design and Process Optimization
(29 months) Apr 2012 – Aug 2014

Phase III: Design Validation and Industrialization
(09 months) Sept 2014 – May 2015

Budget

Total Project Funding

> DOE: $1,499,771

> Recipient: $2,572,953

FY11 Funding Received: $ 42,606 (b)

FY12 Funding Received: $406,658

FY13 Funding Received: $713,810

FY14 Funding Expected: $161,535

FY15 Funding Expected: $175,161

BP1: Oct 2011 – Dec 2012 / BP2: Jan 2013 – Aug 2014 / BP3: Sep 2014 – May 2015

Barriers

Verifying system performance under operating conditions

Allowing for the system to function through multiple retreading

Minimizing overall cost of pumping system including assembly

Partners

Goodyear to be lead & sole participant on this project (c)

> Vendors being used for component / testing parts / assembly / mold rings

> RFP / NDA / JDA issued for supply of prototype parts for Validation Phase III

(a) at time of presentation deadline | (b) Oct - Dec | (c) DOE contract does not include partners/collaborators

Mission: The Goodyear Tire and Rubber Company intends to develop "A System for Automatically Maintaining Pressure in a Commercial Truck Tire."

Objective: Develop and demonstrate an in-tire system for automatically maintaining a set pressure in a commercial truck tire.

> The system, referred to as the Air Maintenance Technology™ or AMT, utilizes peristaltic pump technology to automatically maintain tire pressure at the optimum level.

> The project will consist of research, development, and demonstration activities including both laboratory and test tire demonstrations.

Phases Of Work:

> Planning and initial design (6 months) – creation of project plan and baseline design

> Design and process optimization (29 months) – identify final design for pump, regulator and filter, identify process to build, assemble and test prototype tires and document results

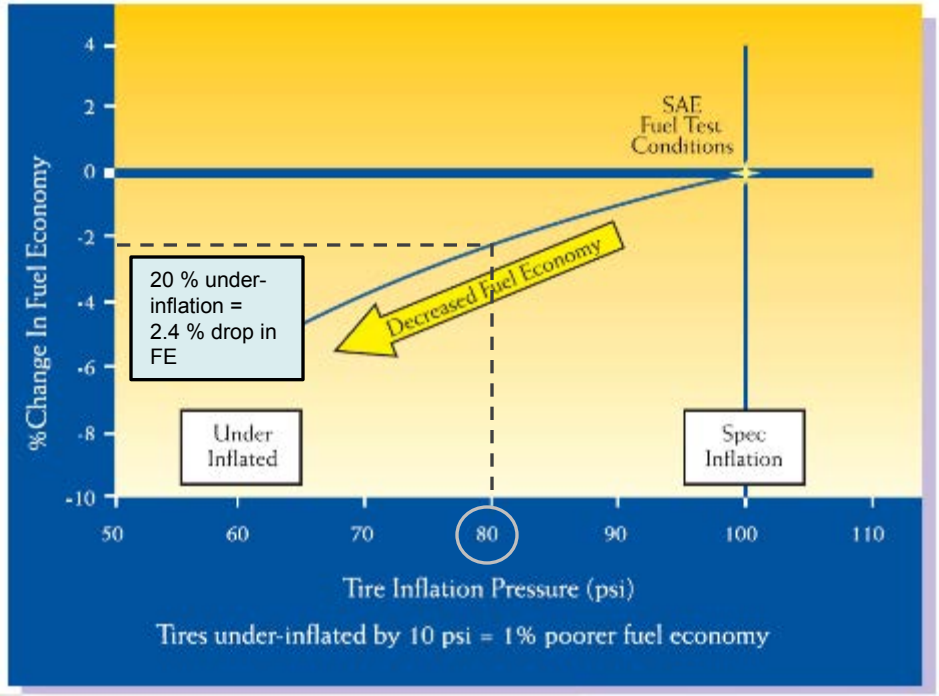
> Design validation, release and industrialization (9 months) – finalize tire system assembly, perform full release testing including vehicle evaluation and industrialize the assembly process

Goals: This technology will have immediate positive impact for drivers in terms of safety and performance; and for the environment through improved fuel efficiency, reduced emissions and extended tire life - while decreasing fleet tire maintenance costs.

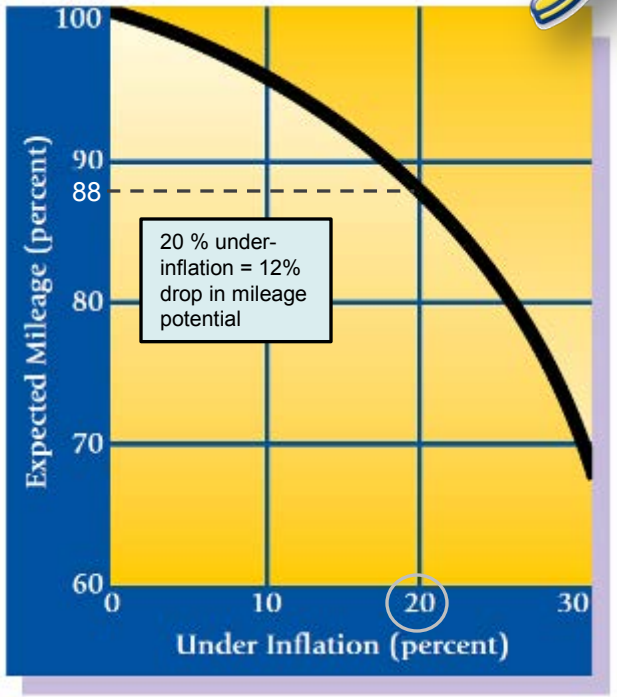
The Air Maintenance Technology™ will most certainly have broad appeal across all classes of vehicles – from small passenger cars all the way up to large commercial trucks.

Relevance

Impact on Fuel Efficiency / Tire Life



http://www.goodyeartrucktires.com/pdf/resources/publications/Factors%20Affecting%20Truck%20Fuel%20Economy.pdf (Page 3)



http://www.goodyeartrucktires.com/pdf/resources/service-manual/Retread_All_V.pdf (Page 40, figure 5.4)

Federal Motor Carrier Safety Administration (FMCSA) research:

> Majority of tires were under-inflated

20-25% dual assemblies were mismatched with regards to tire inflation pressure

Lower inflation causes excessive flexing or deflection and generates heat

> Over time, this can deteriorate the tire casing

Improve Inflation Maintenance > Improve Fuel Economy, Mileage and Tire Life

Roadside Breakdowns

- Data from Goodyear Fleet HQ maintenance service:
  - Long haul fleets incur about 1.5 roadside breakdowns per truck per year
  - 75% of those breakdowns involve underinflated tires
  - 0.75 x 1.5 = 1.125 breakdowns due to under-inflation
- 50% of the active tire population is long-haul
  - 0.50 x 71,000,000 (a) = 35,500,000 tires
- 35,500,000 / 18 (one long haul truck) = 1,972,222 trucks running (b)
- Production of one commercial truck tire requires 22 gallons of oil (c)
- 1.125 x 1,972,222 x 22 gals = 48,812,494 gallons of oil potentially saved per year (1.2 million barrels)
- Additional fuel expenditures from service vehicles making road calls

Numbers above are Goodyear estimates, unless otherwise noted

(a) 2011 Active Tire Population by MacKay & Company (2012)
(b) This number could be larger as a small % of long haul trucks are single axle drive configurations
(c) http://www.sttc.com/reasons-retread-commercial-tires

Reducing roadside breakdowns reduces fleet costs and saves energy

Improve Inflation Maintenance > Improve Fuel Economy, Mileage and Tire Life

Relevance

Milestones

Milestone	Phase 1: Planning and Initial Design (Concept Scoping)	Month	Date
M01	Revised work plan & budget accepted by DOE & Goodyear	01	31-Oct-11
M02	Initial system, component & process specifications complete	06	31-Mar-12
Milestone	**Phase 2: Design and Process Optimization (Prototype Development)**	**Month**	**Date**
Iteration 1			
M03	Initial simulation and modeling complete	09	30-Jun-12
M04	First iteration system assemblies complete	11	31-Aug-12
M05	Evaluation of first design complete	12	30-Sep-12
Iteration 2			
M06	Second iteration system assemblies complete	17	28-Feb-13
M07	Go/No go decision based on evaluation of refined design	18	31-Mar-13
Iteration 3			
M08	Third iteration system assemblies complete	23	31-Aug-13
M09	Go/No decision for on-vehicle trial	24	30-Sep-13
M10	On-vehicle trial initiated – San Angelo	27	31-Dec-13
Iteration 4			
M11	Fourth iteration system assemblies complete - Eaton 1	31	21-Apr-14
M12	Go/No go decision based on evaluation of refined design	32	19-May-14
Iteration 5			
M13	Fifth iteration system assemblies complete - Eaton 2	33	16-Jun-14
M14	Go/No go decision based on evaluation of refined design	34	7-Jul-14
M15	Delivery of regulator/filter components begins from Eaton for fleet testing	34	28-Jul-14
Milestone	**Phase 3: Design Validation**	**Month**	**Date**
M16	Qualification testing completed prior to fleet (customer) evaluation assembly	36	22-Sep-14
M17	Go/No go decision for fleet trial based on qualification testing	36	26-Sep-14
M18	Assembly of fleet evaluation tires commences	36	29-Sep-14
M19	Fleet evaluation initiated	37	15-Oct-14
M20	3 1/2 months fleet evaluation completed	40	31-Jan-15
M21	DOE project completed - 7 1/2 months fleet evaluation completed	44	31-May-15

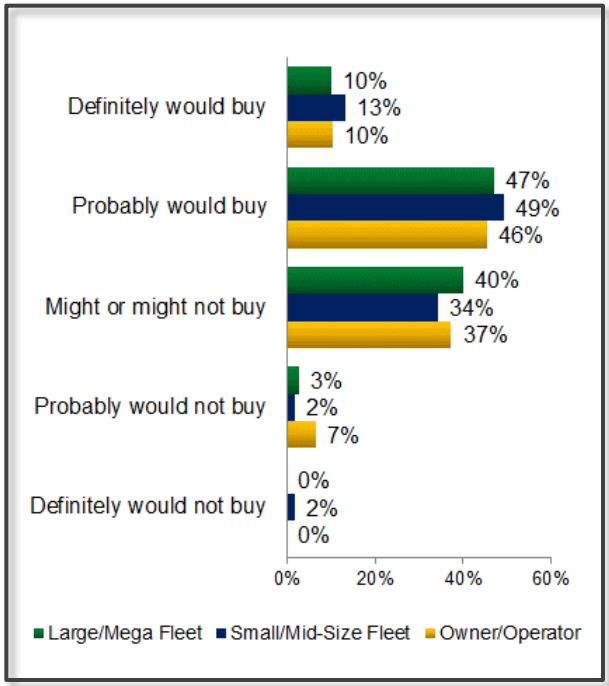
Simplest mechanical system to allow for quick market penetration

- Integrated into tire as a new feature
- Manufacturing process not to be altered significantly
- No special tire handling or mounting equipment
- Can be immediately used by vehicles in service
- Usable on all axles
- Last life of tire through retread

Approach

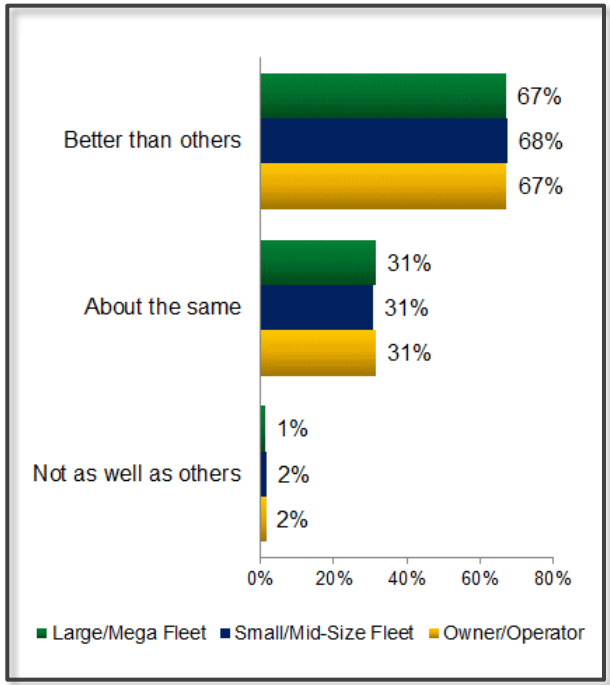
Concept Testing - How do customers respond?

What is the interest?



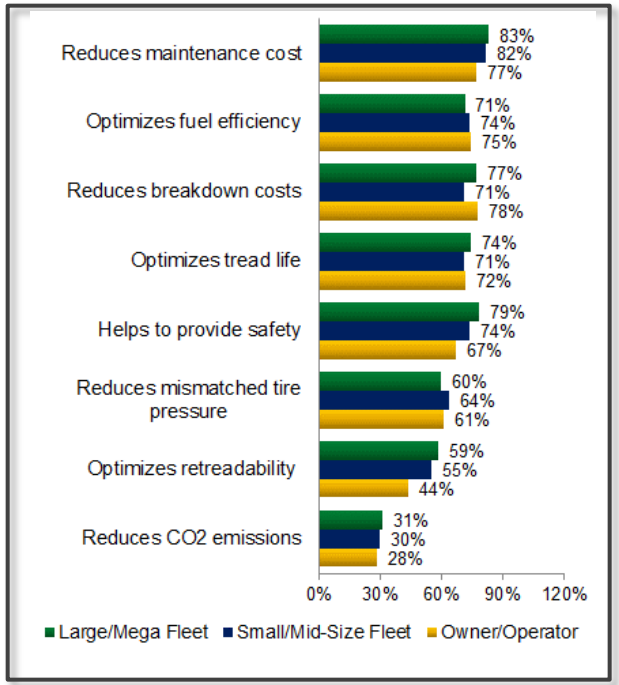
58% probably or definitely would buy

Does it fulfill your needs?



2/3 say that it would meet their needs

Appeal of benefits?

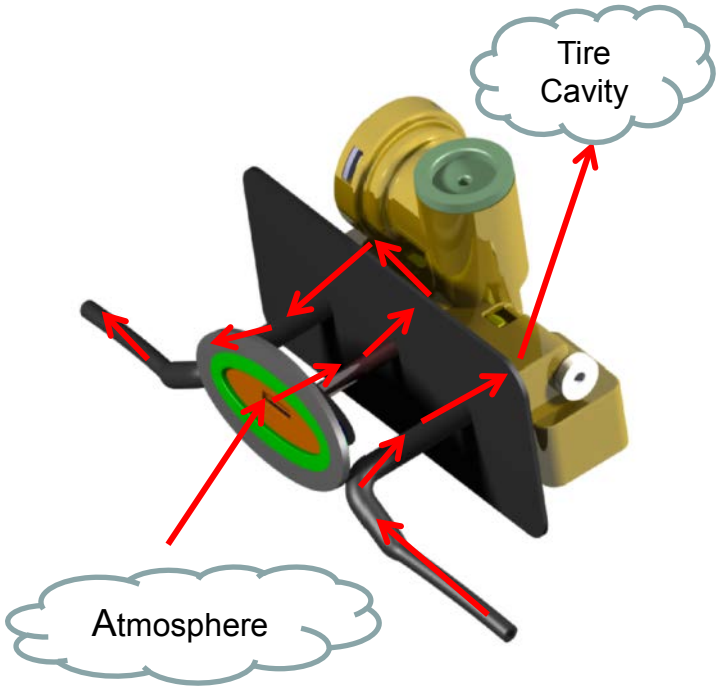


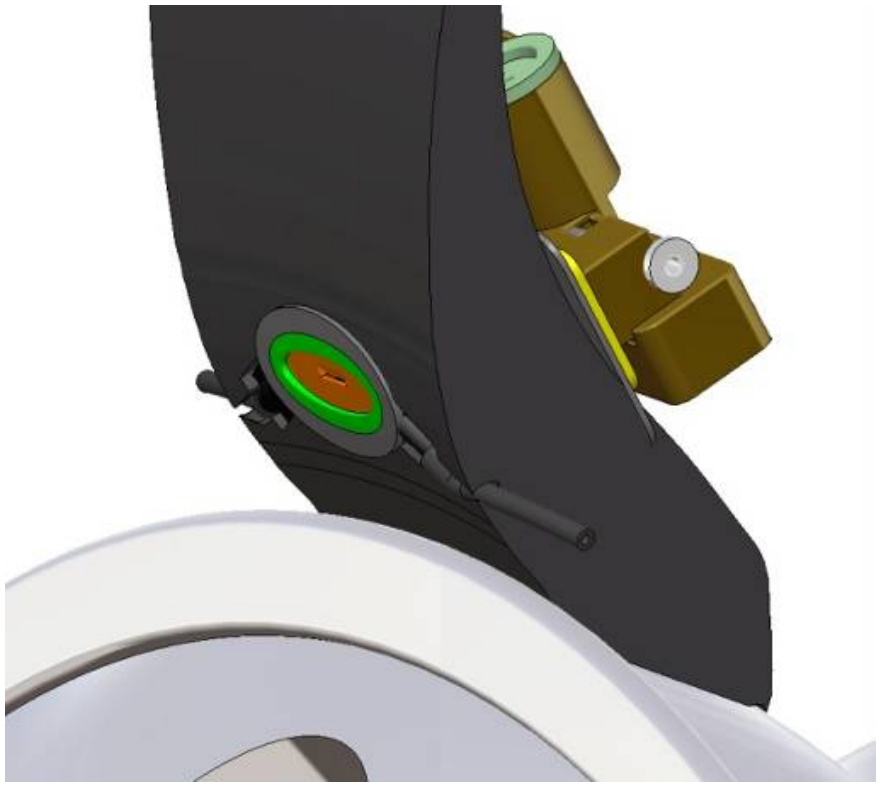
Cost, efficiency and safety drive appeal of AMT

Owner/Op: 1-25 trucks Small/Mid-Size: 26-200 trucks Large: 201-499 trucks Mega: >500 trucks

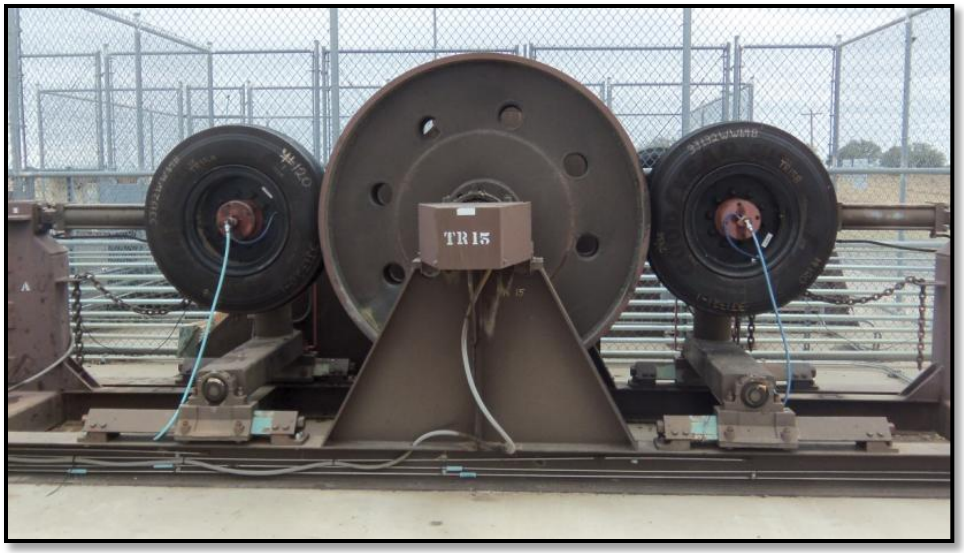
- Design
  - Components optimized
- Laboratory testing
  - High Cycle
  - High Deformation
  - High Speed
- On vehicle tire feature testing
- On vehicle system testing
  - On track in Akron
  - Over the road in Texas

- Regulator
  - Redesigned to lower weight, cg height and overall size
- Pump tubes
  - Compounded to reduce wear
- Passage tubes
  - Move from steel to flexible rubber passages
  - Rubber compounded to maintain clear air passage in severe service


Tire
Cavity
Atmosphere



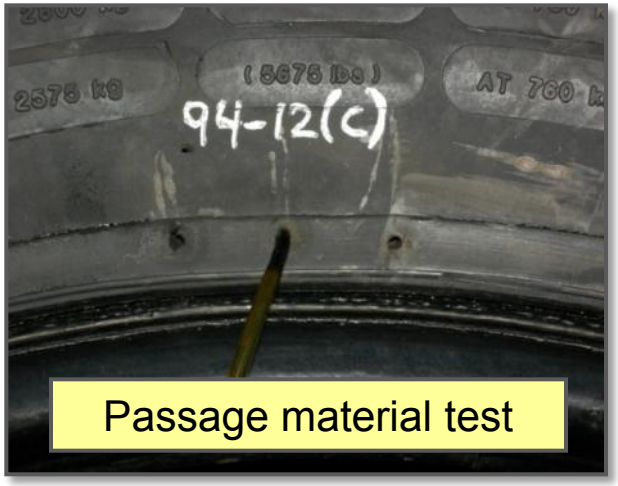
- High mileage test run outside for environmental exposure while applying many cycles to tire simulating normal MRT tire life cycle
  - Standard test does not specifically target area of AMT features & hardware
  - Results are judged relative to control tires and cause for removal
  - Test is run on AMT tires to evaluate the effect of HIGH CYCLES and exposure to weather related factors
- ODR Conclusions
  - 'AMT' tires running side-by-side with controls up to 120K miles
  - **Not experiencing early removal and NOT being removed due to 'AMT' features**



- Step load test, overloaded, under-inflated, destructive test targeting bead area and lower sidewall of tire
  - Test target area is location of AMT tire features and system hardware
  - Results are judged relative to control tires and a minimum performance requirement
  - Bead test effective for evaluating pump tube, passage tube, cover strip, filter retention, and overall AMT tire casing durability
- Bead Durability Conclusions
  - **'AMT' tires are providing adequate bead area durability**

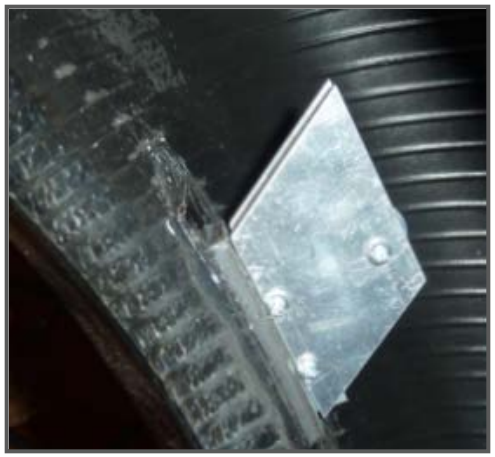

AMT tire after test


AMT tire after test



Passage material test

- Purpose: Evaluate the adhesion of the Regulator Dock against Centrifugal Force
  - Test: Tire is run at increasing speed steps up to 93 mph
  - Initial dock designs did not successfully pass the 93 mph speed step
  - Dock redesigned and attachment process improved
- High Speed Test Results
  - **Dock survives high speed test**

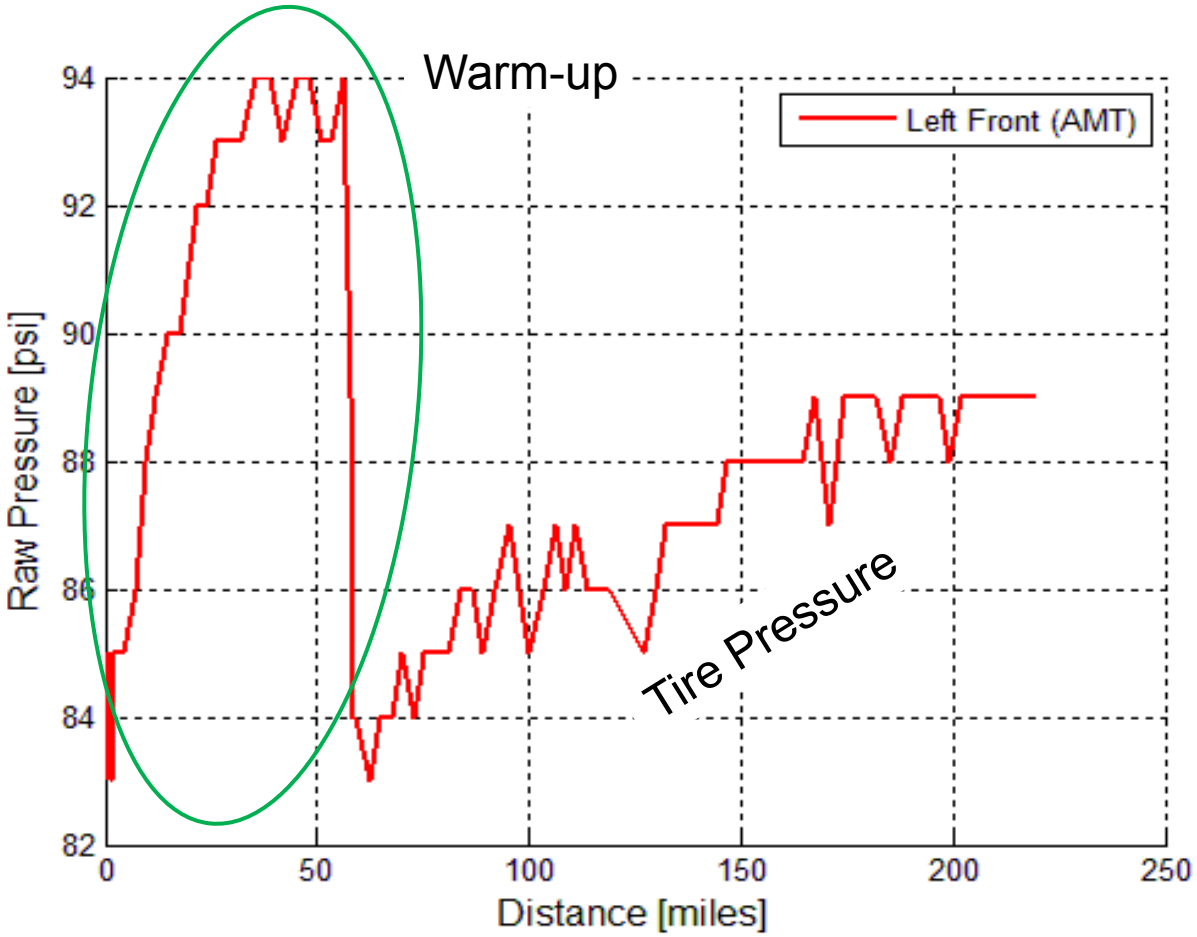


Equivalent regulator mass attached to the adhered dock

- Focus Fleet (external customers) Evaluation
  - As molded tire with AMT features (no AMT system hardware): September, 2013
  - 2 Focus Fleets with 48 tires each run in typical service
  - Periodically inspected, last Inspection at 75,000 miles
- Focus Fleet Conclusion to date
  - **No observed reasons to remove from service**

Technical Accomplishments & Progress

On Vehicle Testing : Akron Truck System Tire Test Data (~5700 lbs @ 45 mph)



	62-219 miles	Goal	
slope	2.01	1.00	psi/100miles

- Warm-up lasted approx 1 hr - 20 min (~60 miles)
- Stop then reset pressure down to 85psi
- Run for 1 shift
- Test run Nov 2013 during annual DOE site visit to Akron

- After 60 miles, tire temperature reaches steady state and additional pressure change is due to AMT pumping
- Variable loads, due to track course, still yield a good pump rate (better than lab tests and greater than goal)

- Vehicle testing in progress since Dec. 17, 2013 at Goodyear San Angelo Proving Ground (SAPG)
- Tires passed required DOT testing to be certified for use on public roads
- System tires fully functional except for pressure regulation
  - Tires pump continuously
  - Tire pressure released on a regular schedule
- 16 tires (5 system and 11 control tires) mounted on truck
  - Mounted on drive and trailer positions
- Tires were equipped with commercial TPMS
  - Data collected for analysis
- Tires also manually monitored for pressure and events

- Test Location and Period: (more than 75,500 miles through end of April)
  - SAPG track from Dec. 17, 2013 to Jan. 10, 2014
    - Basic performance and component evaluation on 8 mile loop, total mileage: 4568 miles
  - Goodyear Truck Tire Wear Route as of Jan. 13, 2014
    - Over public road evaluation on 575 mile loop route
    - 2 shifts per day and 5 days per week (~ 5500 miles per week)
    - Total mileage: 75,500 miles and running
- Average pump rate above 1 psi / 100 miles
- New design tires will replace initial prototypes
  - First prototypes returned for forensics
- Testing will continue through 2014 (and could extend further)

Technical accomplishments and progress toward overall project and DOE goals – the degree to which progress has been made, measured against performance indicators and demonstrated progress toward DOE goals.

Reviewer 3 Comment:
The reviewer observed that the project had overcome some barriers with possible successful approaches, for example, designing redundant check valves to prevent leaks, and replaceable filters. However, the reviewer opined that more emphasis on tire durability and reliability is needed, as well cost.

Goodyear Response:
Goodyear agrees with the reviewer and has been subjecting the AMT design and components to numerous durability and reliability testing as detailed in slides 09-18 of this presentation. Goodyear also worked with our suppliers to redesign components in order to lower weight, cg height, overall size and subsequently the cost of the components.

Proposed future research – the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 2 Comment:
The reviewer indicated that the project had excellent and realistic milestones set. The timelines were reasonable to achieve objectives.

Goodyear Response:
Although Goodyear agrees with the reviewer, Goodyear requested a no-cost extension to this project. The project extension adds eight (8) months to the overall timeline. This will enable Goodyear to provide sufficient and meaningful focus (fleet) data to the DOE in the final report. Per the new timeline, the Milestone log was modified and is shown on slide 06.

Filter assembly

Regulator in lab test

- Design Progress
  - Regulator design simplified
  - Regulator size and weight reduced
  - Regulator dock attachment design improved for retention
  - Filter holder mechanically decoupled from tire motion
  - Materials selected for good mechanical performance and rubber adhesion
- Prototypes received
  - Regulators, docks, filter holders and filter covers
  - Prototypes are in testing
    - Lab component performance
    - On tire tests on road wheels and vehicles

Proposed Future Work

Focus (Fleet) Testing – 2014 start

Test 1: Focus Evaluation for Pumping, Durability, and Environmental Extremes

- 45 tractors, 15 each in moderate, hot, and cold climates
  - Each tractor to include a mix of (4) AMT and (4) non-AMT (control) tires on front and rear drive axles

180 new AMT and 180 controls on 45 tractors
Pressure set selection required for AMT regulator specification

Test 2: Focus Evaluation for Pumping and Durability of Retread Tires

- 6 trailers equipped with 4 retread AMT and 4 retread controls (same casing and retread design) on trailer axle

24 AMT retreads and 24 retread controls on 6 trucks
Pressure set selection required for AMT regulator specification

Monitoring:

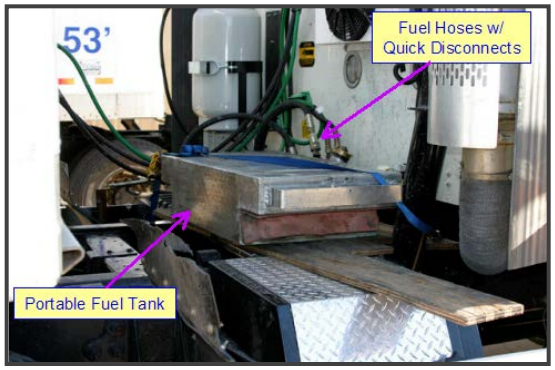
- Acquire pressures & ambient temperature weekly or at least monthly on all tires
- Visually Inspect tires and AMT system components regularly
- Track any maintenance and air adjustments

Proposed Future Work

Fuel Economy Testing (San Angelo Proving Ground, TX) - 2014

Fuel Test Tractor/Trailer

Portable Fuel Tank



8-Mile Test Track, SAPG

Fuel Consumption Test Procedure (planned procedure):

- Joint TMS/SAE Fuel Consumption Test Procedure – Type II, SAE J1321 to be considered
- One truck with AMT tires – one truck with control tires (non-AMT)
- Trailers will be loaded with concrete blocks to provide a gross vehicle weight of ~80,000 pounds
- All tires will run a 200 mile break-in before the start of the fuel consumption test.
- After warm-up is completed, tire pressures will be re-set to test conditions (variable to simulate range of pressures)
- Each test segment will be made up of a minimum of 3 test runs, with each run consisting of 5 laps around the 8 mile track
- The pounds of fuel used during each test run will be measured

Proposed Future Work

2014

- Additional development tire build iterations in Topeka, Kansas manufacturing facility (295/75R22.5 G572A): April, May & June ship dates
  - Produce new design with integrated filter holder and optimized passage spacing
  - Further refinement of pump tube geometry for improved performance
- Continue to define and refine system, component and process designs
  - Evaluate new passage and pump tube material selections and new regulator attachment method
  - DFMEA / PFMEA
- Continued performance and durability testing
  - Longer term trials at San Angelo test facility
    - 100,000 mile road wheel tests
    - Over the road testing
  - System tire retread evaluations
- Initiate focus fleet vehicle trial
  - Finalize design
  - Procure components from suppliers, produce trial tires and assemble into systems
  - Retread a group for testing
  - Install new and retreaded tires on target trucks
  - Initiate monitoring of system performance

Summary

- ☑ Several design iterations completed for tire and components
- ☑ Regulator size and weight reduced
- ☑ Improved component attachment methods developed
- ☑ Pump and passage tube materials refined for durability
- ☑ High deformation, high cycle and high speed lab testing completed on prototypes
- ☑ On vehicle testing of systems underway since Dec 2013
- ☑ All milestones met to date
- ☑ 14 US Patents granted, additional filings in process
- ☑ Project on track

(Summary items as of 15-April-2014)