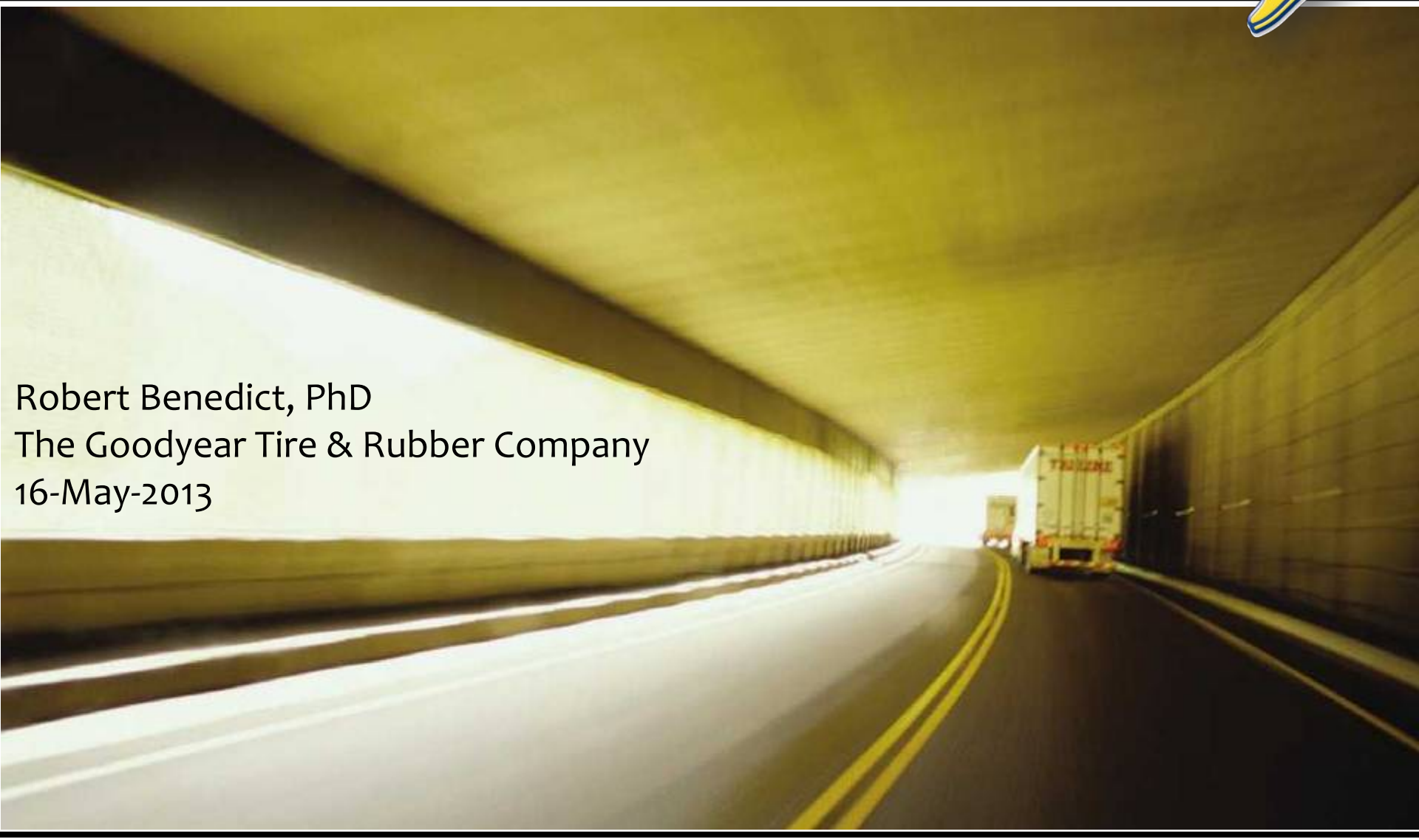
A System for Automatically Maintaining Pressure in a Commercial Truck Tire



Robert Benedict, PhD
The Goodyear Tire & Rubber Company
16-May-2013

Timeline

Project Start – 01-Oct 2011

Project End – 01-Oct 2014

Percent Complete – 48% *

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

Phase II: Design and Process Optimization
(18 months) Apr 2012 – Sep 2013

Phase III: Design Validation and Industrialization
(12 months) Oct 2013 – Sep 2014

Budget

Total Project Funding

> DOE: $1,500,000

> Recipient: $2,572,953

FY11 Funding Received: $ 42,606 **

FY12 Funding Received: $406,658

FY13 Funding Expected: $735,216 ***

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 ****

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

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

* at time of presentation deadline | ** Oct - Dec | *** $225,350 unused from BP1 (FY11/FY12) | **** 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:

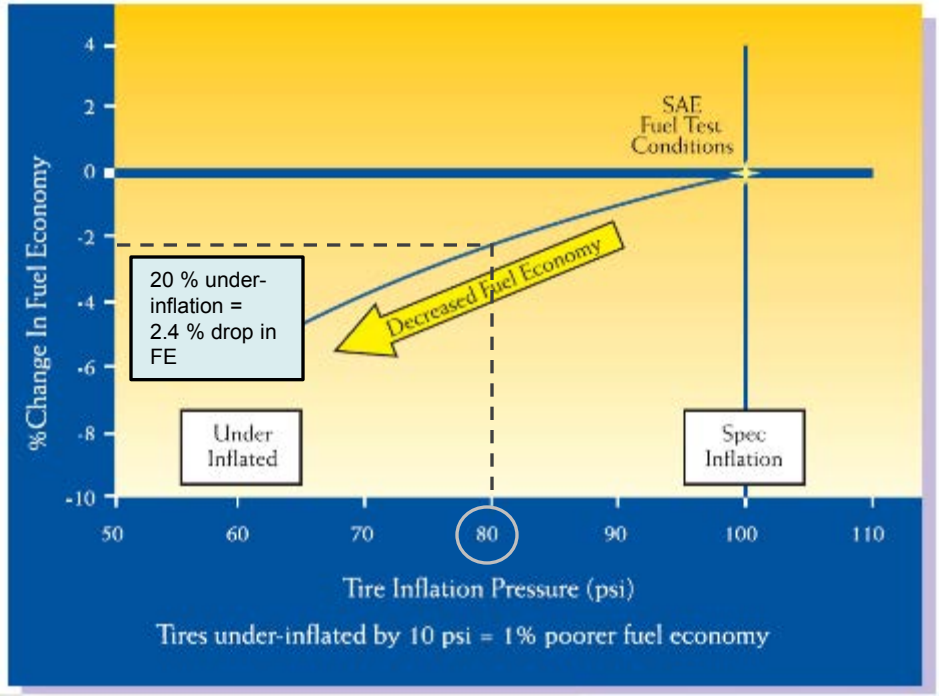
> Planning and initial design (6 months) – creation of project plan and baseline design

> Design and process optimization (18 months) – identify final design for pump, regulator and filter, identify process to build, assemble and test prototype tires and document results

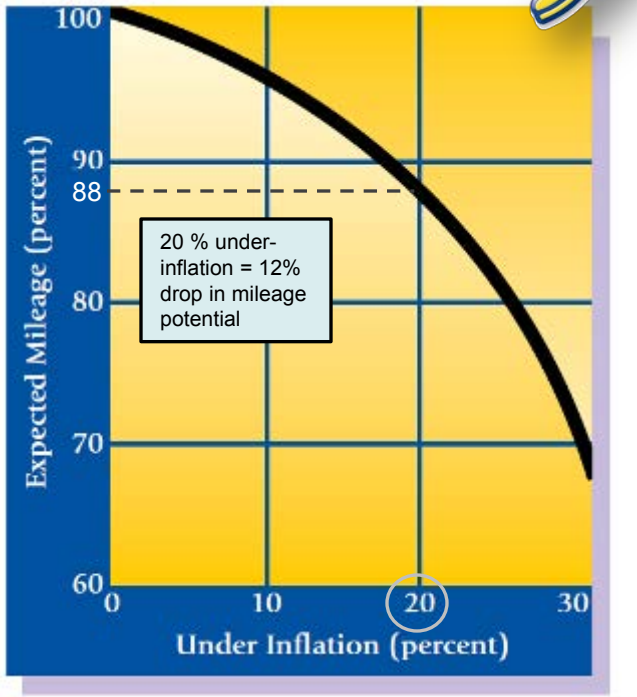
> Design validation, release and industrialization (12 months) – finalize tire system assembly, perform full release testing including vehicle evaluation and industrialize the assembly process

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.



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

Phase 1: Planning and Initial Design (Concept Scoping)	PLAN
M01. Revised work plan & budget accepted by DOE & Goodyear – Month 1	31-OCT-11 ✓
Month 1 not appropriate – revised budget submitted 09-Dec-2011	
M02. Initial system, component & process specifications complete – Month 6	31-MAR-12 ✓
Phase 2: Design and Process Optimization (Prototype Dev'p)	
Iteration 1	
M03. Initial simulation and modeling complete – Month 9	30-JUN-12 ✓
M04. First iteration system assemblies complete - Month 11	31-AUG-12 ✓
M05. Evaluation of first design complete – Month 12	30-SEP-12 ✓
Iteration 2	
M06. Second iteration system assemblies complete - Month 17	28-FEB-13 ✓
M07. Evaluation of second system tire – Month 18	31-MAR-13 ✓
Iteration 3	
M08. Third iteration system assemblies complete - Month 23	31-AUG-13
M09. Go/No decision for vehicle trial – Month 24	30-SEP-13
Phase 3 : Design Validation and Industrialization	
M10. Production of final prototypes complete – Month 27	31-DEC-13
M11. On-vehicle trial initiated – Month 27	31-DEC-13
M12. On-vehicle trial 50% completed – Month 30	31-MAR-14
M13. On-vehicle trial completed – Month 36	30-SEP-14

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

Objective: establish a turn-key, quantitative methodology to test & validate the customer-back need of new products & services by fleets (end users)

Recruit: panel of fleets, broken out into segments (long haul, regional, etc), vocations (food & beverage, waste haul, etc) and size of fleet; small (1 – 25) to large (over 500)

Concept Test: includes a one-page concept board, with key messages, potential savings, image and features & benefits, along with a questionnaire to gage interest

Deliverables (partial list):

- Ranking of features & benefits
- Uniqueness
- Impressions
- Purchase intent
- Perceived value & price
- Technology insight

Field survey began 19-Nov-2012
150 fleets / 30+ questions
Results 8-Jan-2013
Conducted by Decision Analyst

Scenarios

- Concept boards presented either a $1000 yearly savings or a $2000 yearly savings
- Distribution from owner/operators (23%) through mega fleets of 500+ vehicles (23%) was fairly even
- About 97% of motor carriers have fewer than 20 trucks
- 50% were Goodyear customers and 50% were competitor customers

Interest in Purchasing Strong

- 91% of those surveyed definitely, probably or might buy
  - Only 9% said 'probably not'
- No respondents answered 'definitely not'

Product Feature Recommendation

- Customers prefer that regulator and filter are replaceable elements

Key Imagery

- AMT is viewed as being very advanced, innovative, and unique. It is also seen as being fuel efficient and good for the environment.

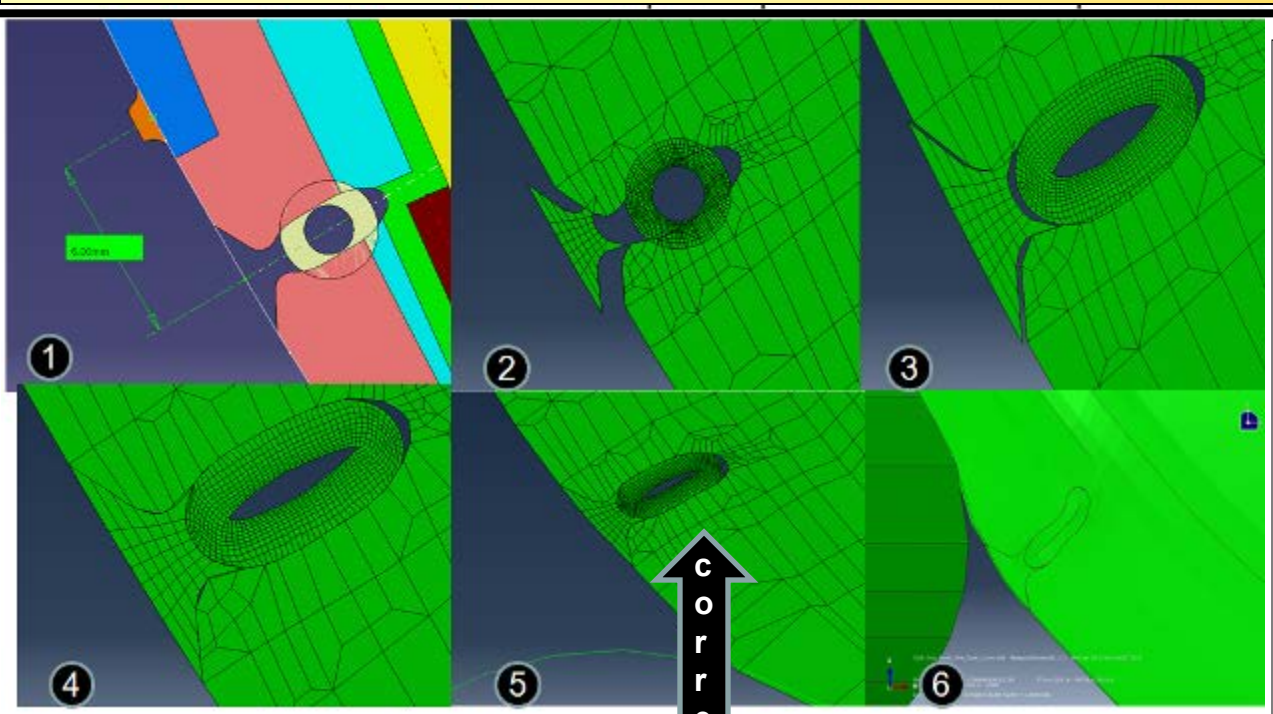
Survey Participation

Business Type	Total
Regional Fleet	35%
Line Haul	31%
Mixed Service	26%
Urban	8%

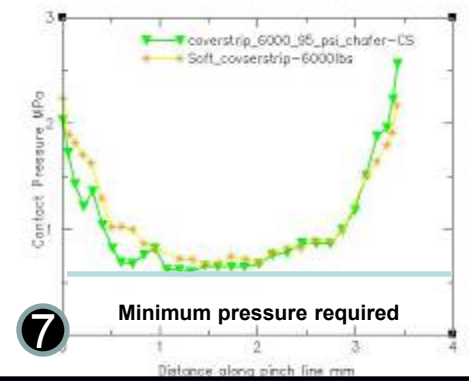
Fleet Size	Total
Owner/Operator (1-25)	23%
Small Fleet (26-100)	22%
Midsize Fleet (101-200)	17%
Large Fleet (201-499)	15%
Mega Fleet (500+)	23%

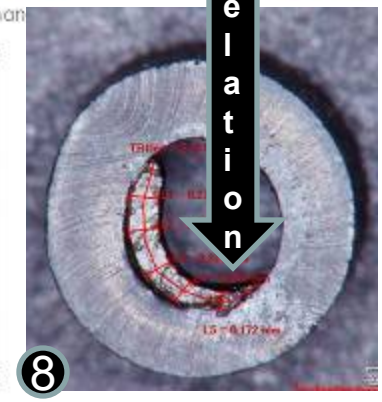
Technical Accomplishments & Progress

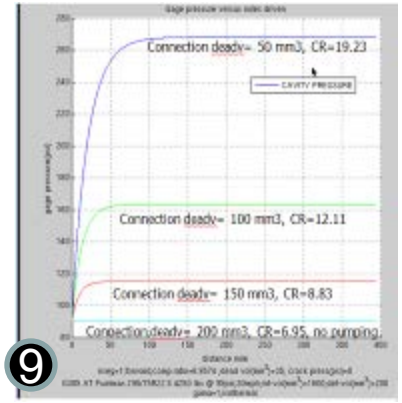
Groove & Tube Shape Design & Modeling Process



correlation



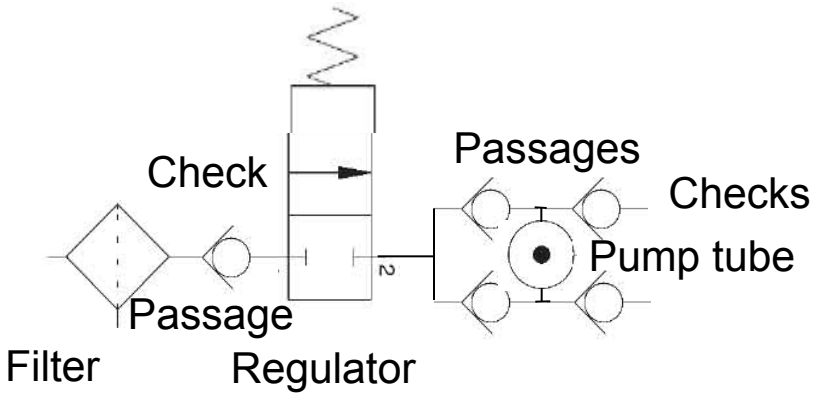


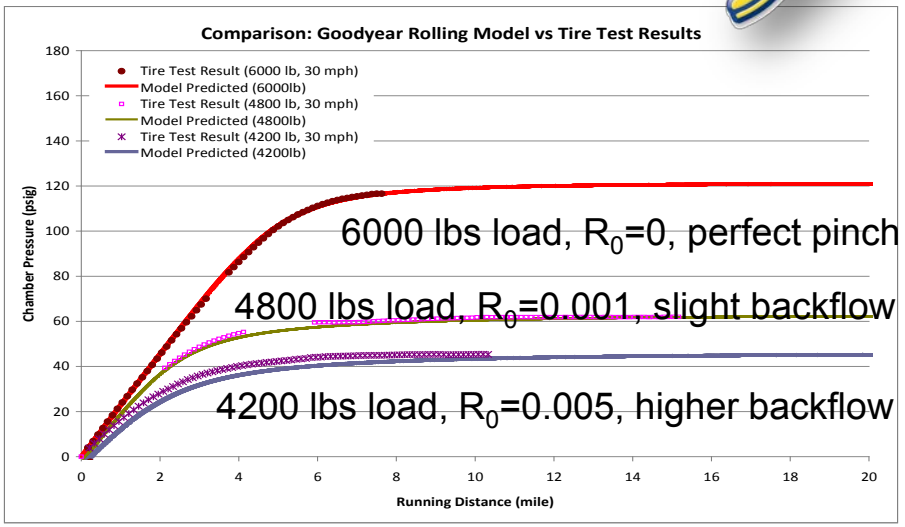


1. Initial design of the groove shape located from the reference gg groove
2. Tube & Cover strip in initial uninstalled position
3. Tube is installed first.
4. Cover strip is installed , tire is still un-mounted.
5. Verify the design requirement that the tube has to be open at the mount and inflated condition
6. Verify the design requirement that the tube is fully pinched at the loaded condition of the tire
7. Verify the design has enough contact pressure at the fully pinched condition.
8. Verify the predicted mount & inflate opening by urethane measurement
9. MATLAB® prediction of pumping performance via thermodynamic analytical modeling

Design process developed and applied to improve product performance

Pump System Schematic

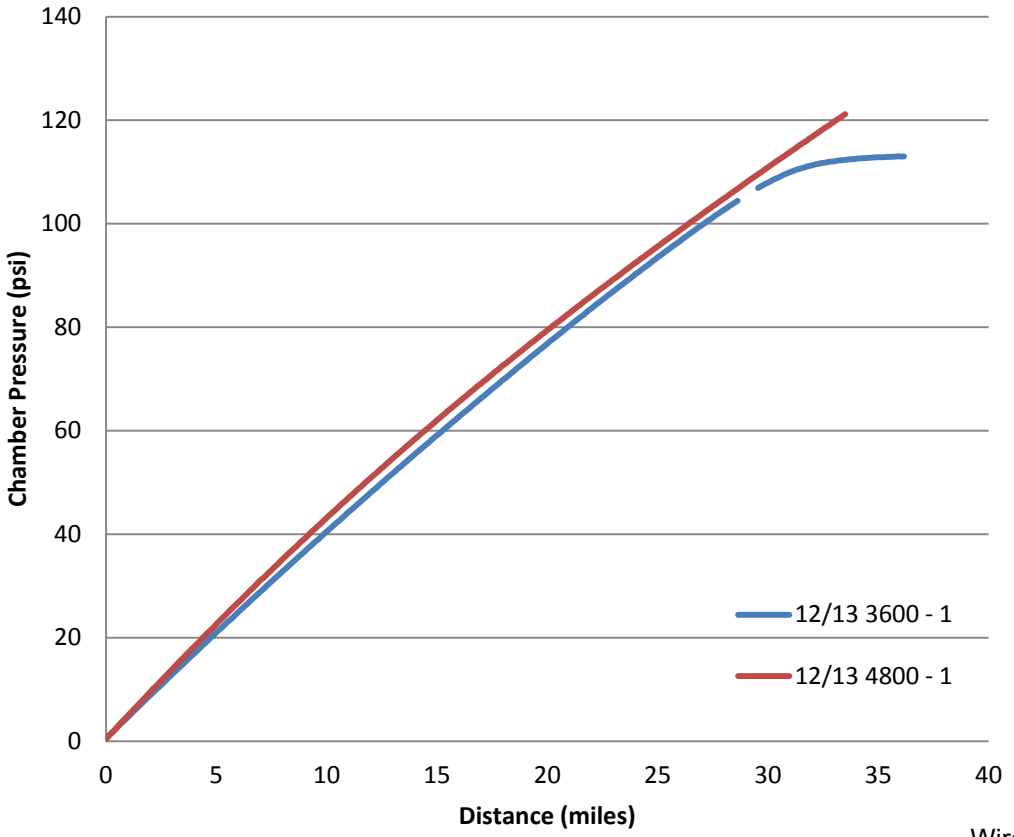




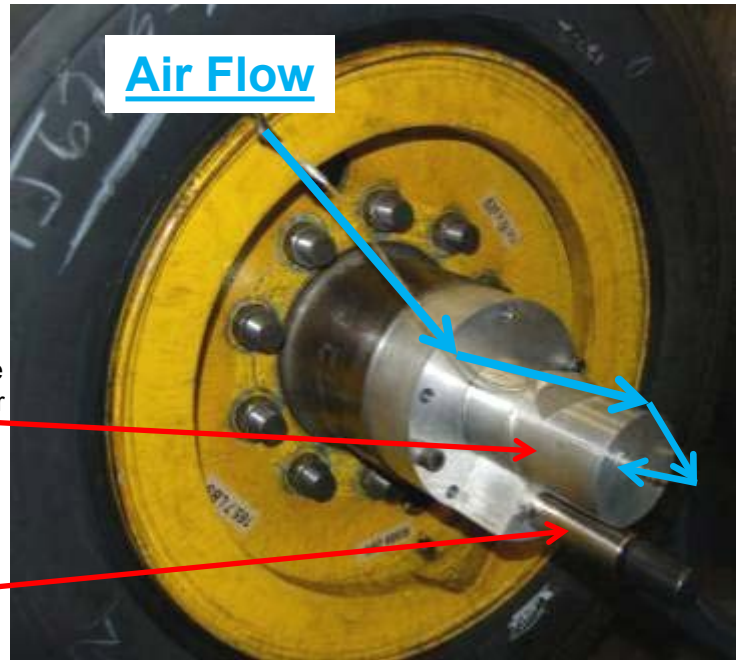
- Improved system dynamic model developed along with laboratory tests to establish model parameters
- System model includes
  - Pump tube with moving pinch including possible leak back from partial pinch
  - Filter flow pressure drop
  - Passage tubes pressure drop
  - Check valve cracking pressure and pressure drop
  - Dead end volumes
  - Regulator performance model with flow restriction dependant on sensing pressure

System Model Including Relevant Air Flow Parameters Developed and Verified

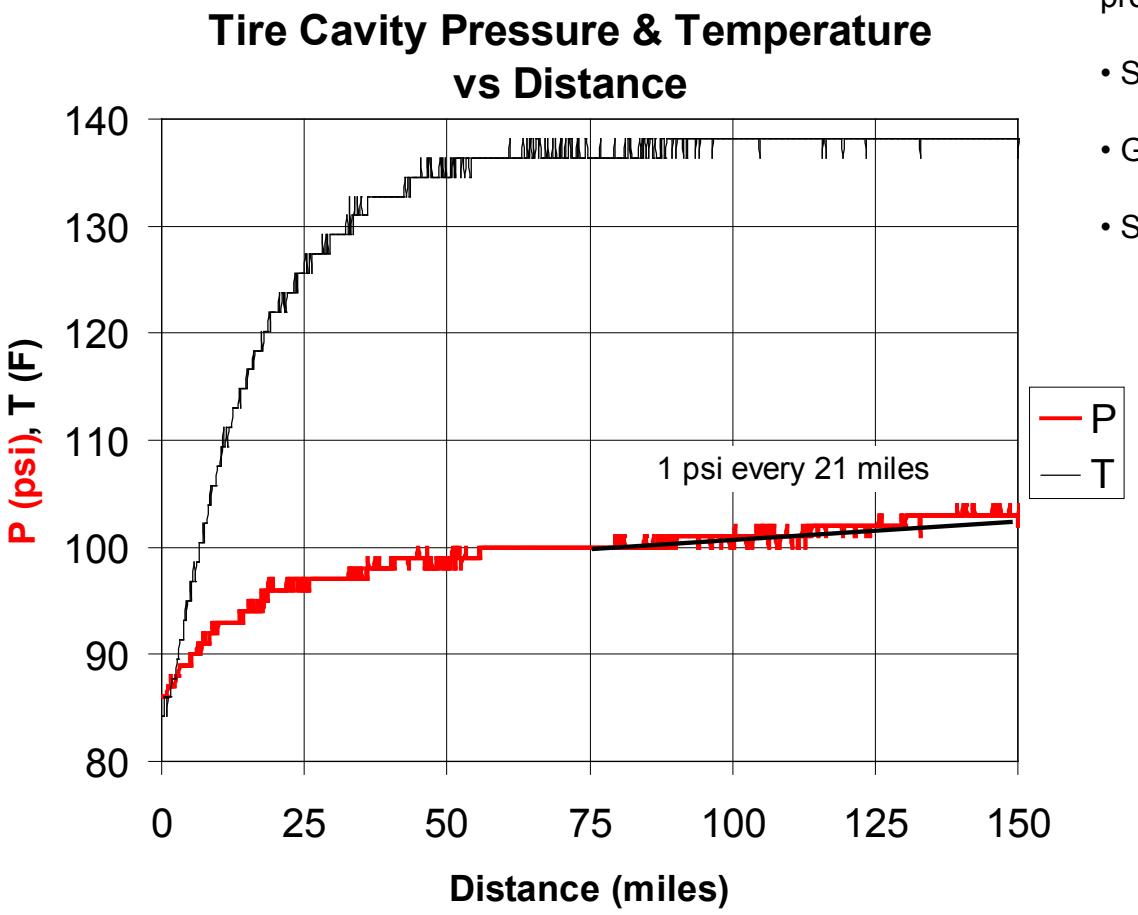
Summary 1J6293-202 Pump Test



- Pump simulation tests with tube routed to chamber with pressure monitoring
- Tube pushes air into empty chamber until it can push no more
- Graph shows two different groove shape designs and how the pump performance varies at different loads.



Pumping Theory Proven / Vehicle Evaluation to begin 4Q2013



- Pump test through passage into tire with cavity pressure and temperature monitoring
- Simplified regulator with check valve only
- Graph shows pressure and temperature rise
- System pump rate targets met

Tire with integrated pump tubes, passages and check valves

Initial System Validated by Testing

Adhesion test

Tubes inserted in groove

Tubes under cured rubber cover strip

- Thermal cure
  - Typical vulcanization under heat and pressure
  - First trials used retreading equipment
  - Production would use specialized platens
    - Prototype platen designed, produced and in use for prototyping
- Chemical cure
  - Two part mixtures that cure at room temperature after mixing
  - Process cost advantage
- Testing
  - Good durability results observed in testing of thermal cure prototype tires
  - Chemical cure evaluation started

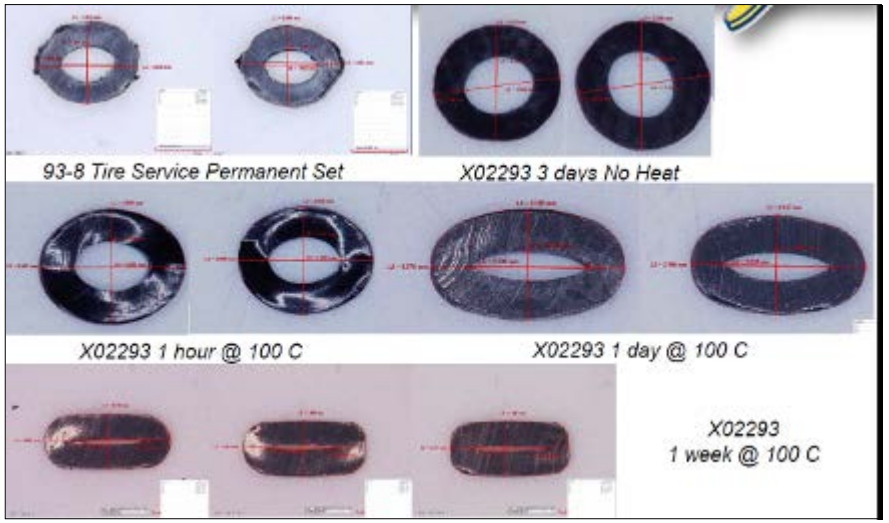
Heated platen

Prototype Manufacturing Method Developed and Cost Reduction Under Study

- Important material properties
  - Permanent set
  - Elasticity after aging
  - Abrasion resistance
  - Resistance to damage from solvents and adhesives

Deflection driven permanent set test

- Tests developed and applied to candidate materials
  - Material specification updated
  - Anticipated long term durability concerns addressed



Material Requirements Refined

System:

> Pumping Rate: 1 psi pressure increase of tire pressure within 100 miles (~50,000 cycles)
> Pump provides > 140 psi
> Temperature Ranges:
- Ambient: -40°F to 110°F
- In service: -40°F to 215°F
> Survives retread cure: 310°F
> Survives standard tire handling, mounting and dismounting

Regulator

> Weight Limits: Regulator: </= 5 oz
> Pressure Range: 90 – 120 psi
> Regulation accuracy: 2 psi

Filter

> Weight limit: </= 3 oz
> Prohibits liquid and particle entry

Pressure and Temperature Ranges Addressed / Supplier Selected

Product requirements and environment

> Fleet survey completed (collaborative effort with Goodyear marketing)
  - Specification updated with results
> Visits to tire retreading facilities to develop service conditions for product requirements

Synergy / Knowledge Transfer with Consumer AMT development team (Luxembourg)

> Received government grant for research & development of an AMT system
> Regular knowledge sharing with teams in both Akron and Luxemburg Innovation Centers

Four (4) vendor/supplier contracts completed; Sam Landers, AMB, Logan and Eaton

> Sam Landers; former Goodyear R&D Fellow, design advisor
  - 42 years at Goodyear / over 60 Patents (Aquatred / TripleTred)

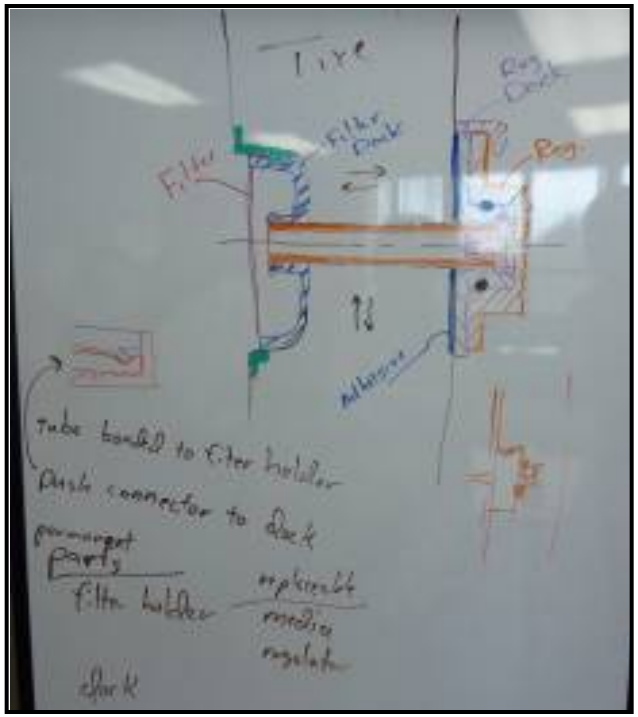
> AMB (American Machine Builders) - Stow, Ohio
  - Manufacturing facility will provide fabrication of devices used to develop prototype tires

> Logan Machine Company – Akron, Ohio
  - Fabrication support for test jigs, fixtures, molds and prototype parts

> Eaton Vehicle Group – Fuel Emissions & Powertrain Controls – Southfield, Michigan
  - Joint development of air management components

- Air management components to be provided by a supplier
  - > Regulator, filter, check valves
  - > No specific expertise or manufacturing capability at Goodyear
- Initial component specifications developed
- Three suppliers provided initial prototypes for evaluation
- Prototypes evaluated and evaluation matrix completed
- Single supplier selected for development collaboration
- Development agreement completed
- Prototypes evaluated and functional design updated
- Joint design development and review meetings held
- Integrated filter/ passage/ regulator design developed

Face-to-face meetings with Eaton for Design Review



Design Responsibilities

Goodyear

- Functional specifications
- Overall system architecture and geometry
- Passage tube design
- Dock adhesion system
- Filter holder pocket
- Filter holder adhesion
- Assembly process
- Retread process
- System DFMEA

Eaton

- Regulator design
- Filter media selection
- Dock material selection
- Component production method
- Regulator mount to dock design
- Regulator DFMEA
- Filter DFMEA

Current Project Plan Layout

1 Build Concept Prototypes ✓

2 Create Detail Drawings for Molded Prototypes ✓

3 Initial Prototype Design Review ✓

4 Prototype Design Review at Goodyear ✓

5 Dock Attachment & Design Detail & Internal ✓

6 Prototype Design Review and Freeze ✓

7 Obtain Prototype Quotes – March, 2013

8 Kickoff from Goodyear for molded prototype tooling – March, 2013

9 Build Prototype Tools – May, 2013

11 Deliver 1st Molded Prototypes – June, 2013

Proposed Future Work

2013

- Additional development tire build iterations in Topeka, Kansas manufacturing facility (295/75R22.5 G305 AT): March and May 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
  - Evaluate 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 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

- ☑ First design built, evaluated and results used to refine subsequent design
- ☑ First prototype components designed, fabricated and exercised in testing
- ☑ Refined design built and initial evaluation completed
- ☑ Component supplier selection process completed, supplier selected, agreement completed
- ☑ Integrated component design with supplier completed
- ☑ First system tires fabricated and tested – pumping rate of 1 psi every 21 miles
- ☑ Specialized laboratory test equipment designed and fabricated
- ☑ Prototype manufacturing fixtures design, built and in use
- ☑ Improved component attachment method developed
- ☑ Improved pump tube integration method developed
- ☑ Pump tube material tests developed and applied to material selection
- ☑ Improved pump system model developed, verified and in use in design
- ☑ Project on track

(Summary items as of 15-March-2013)