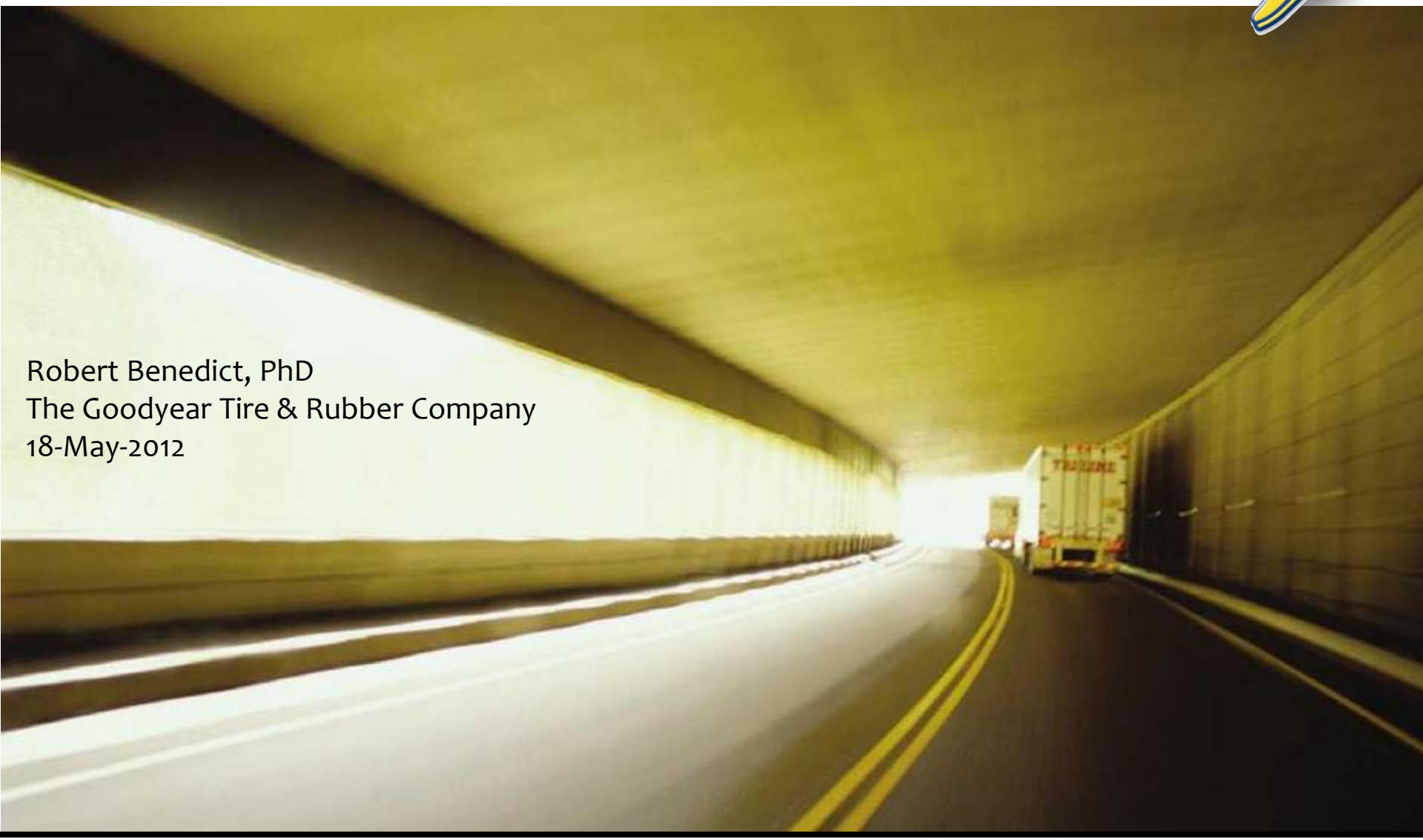
A System for Automatically Maintaining Pressure in a Commercial Truck Tire



Robert Benedict, PhD
The Goodyear Tire & Rubber Company
18-May-2012

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

Project Start – 01-Oct 2011

Project End – 01-Oct 2014

Percent Complete – 15% *

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 Release and Industrialization
(12 months) Oct 2013 – Sep 2014

Budget

Total Project Funding

> DOE: $1,500.000

> Recipient: $2,572,885

FY11 Funding Received: $ 42,606 **

FY12 Funding Expected: $594,572

Barriers

Verifying system performance under operating conditions

Allowing for the system to function through multiple retreading

Minimizing overall cost of pumping system

Partners

Goodyear to be lead & sole participant on this project ***

> Vendors to be used for some initial component / testing parts

> RFPs / NDAs in process for supply of prototype parts for Validation phase

* at time of presentation deadline

** October - December

*** DOE contract does not include partners / collaborators

Relevance - Objectives

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 release and industrialization (12 months) – finalize tire system assembly, perform full release testing including fleet evaluations and industrialize the assembly process

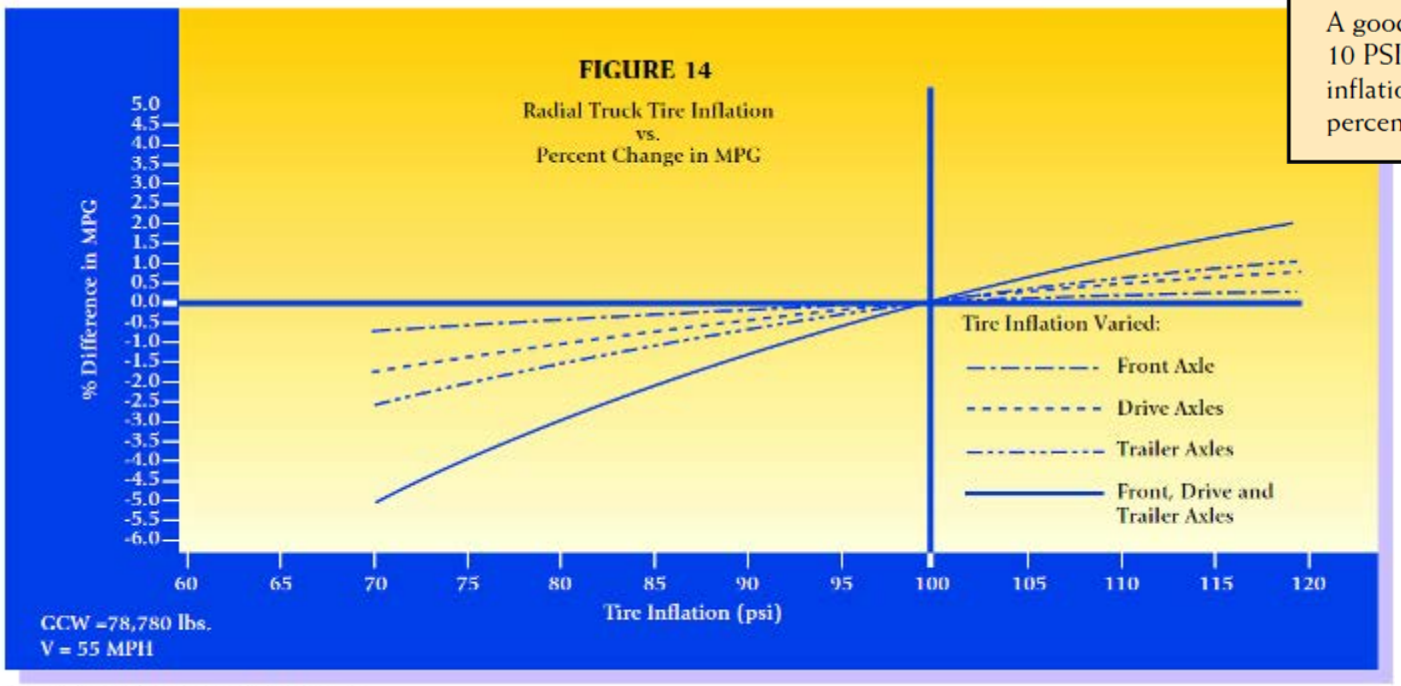
Goals: This technology will have immediate positive impact for drivers in terms of safety and performance; and for the environment through improved fuel efficiency, reduced emissions and extended tire life - while decreasing fleet tire maintenance costs .

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 - Objectives

Fuel Efficiency: Under-inflated tires significantly reduce a vehicle's fuel efficiency by increasing rolling resistance (drag force).

The Air Maintenance Technology system developed through this project replenishes lost air and maintains optimal tire cavity pressure whenever the tire is rolling in service, thus improving overall fuel economy by reducing the tire's rolling resistance.



A good rule of thumb is that every 10 PSI reduction in overall tire inflation results in about a one percent reduction in MPG.

Source: Goodyear Fuel Economy Model Predictions

http://www.goodyear.com/truck/pdf/radialretserv/Retread_S9_V.pdf

Relevance - Milestones

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 field 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

Pressurized air in the tire cavity naturally escapes by diffusion through the tire and wheel, leaks in tire seating, and through the filler valve and its seating.

> As a result, tires require constant maintenance to replenish lost air.

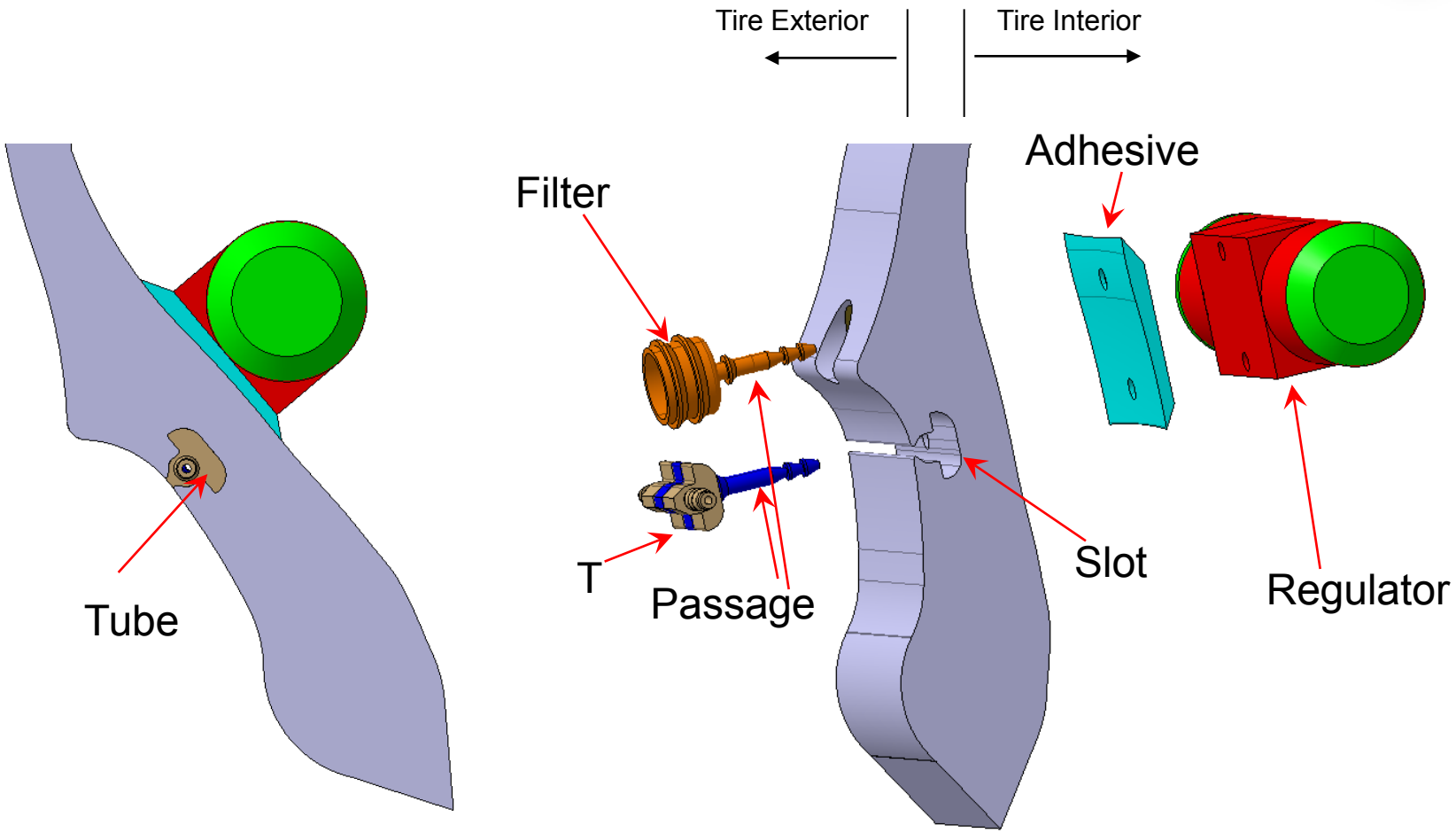
> Since manual tire inflation maintenance is both labor intensive and time consuming, it is frequently overlooked or ignored.

Our system consists of an inlet filter, an air pump driven by tire deformation during rotation, an air passage through the tire, and a pressure regulating device.

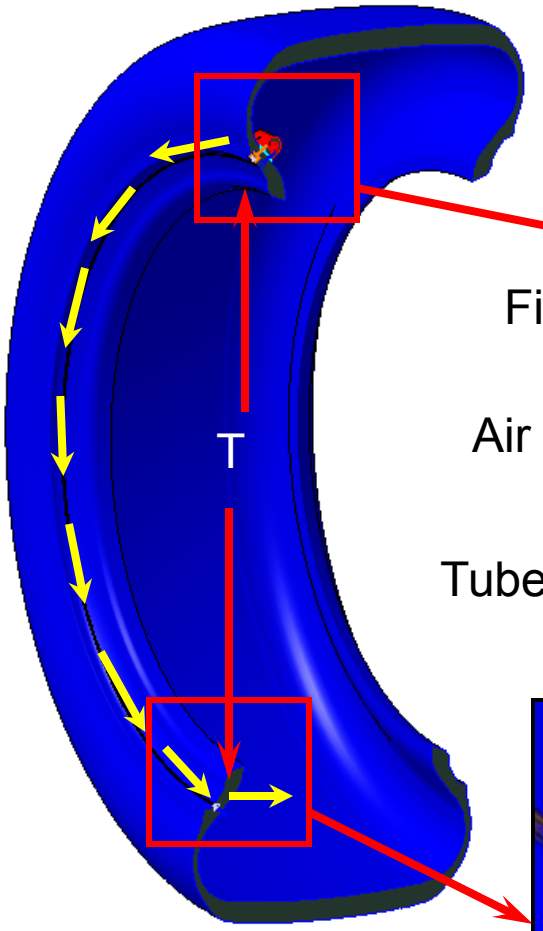
> All required components of the system – including the pump, regulator, and connectors – will be fully contained within the tire.

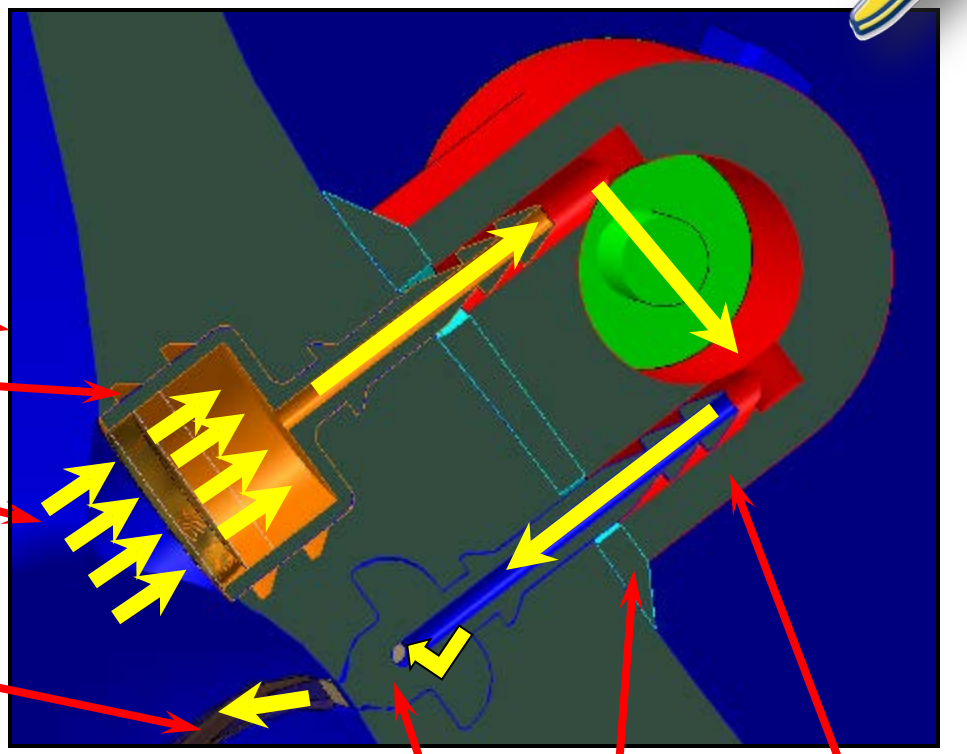
> By automating the maintenance of optimal tire pressure, the tire's contribution to the vehicle's overall fuel economy can be maximized.

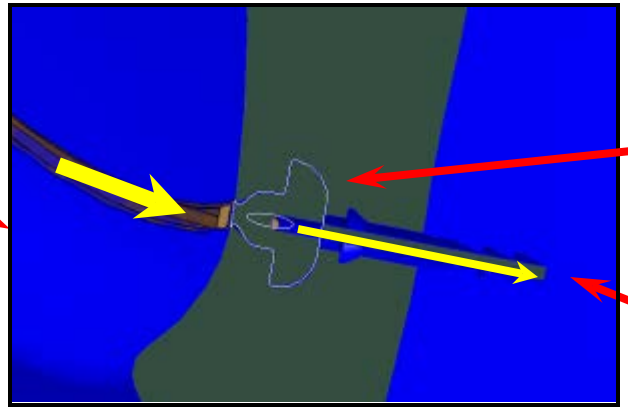
Approach: Component Concepts



Approach: AMT Layout and Assembly







2 x 180 pumps with
Ts to feed and collect

Pump operation

> The internally mounted regulator senses when the tire internal inflation pressure has dropped below the SSP (Specified Service Pressure).

> The regulator opens to allow air to flow in through the filter passing into the pumping tube.

> Tire deformation and rotation induces air displacement to the inlet, where the air then flows into the tire cavity, resulting in increasing the internal tire pressure.

Pump Design Methodology

> Product specification yields tire service conditions and pumping targets

> Basic pump thermodynamic models drive physical targets

> Finite Element tire deformation analysis used to evaluate designs

- Predicted deformations drive Matlab thermodynamic models
- Design iterations to select design candidates

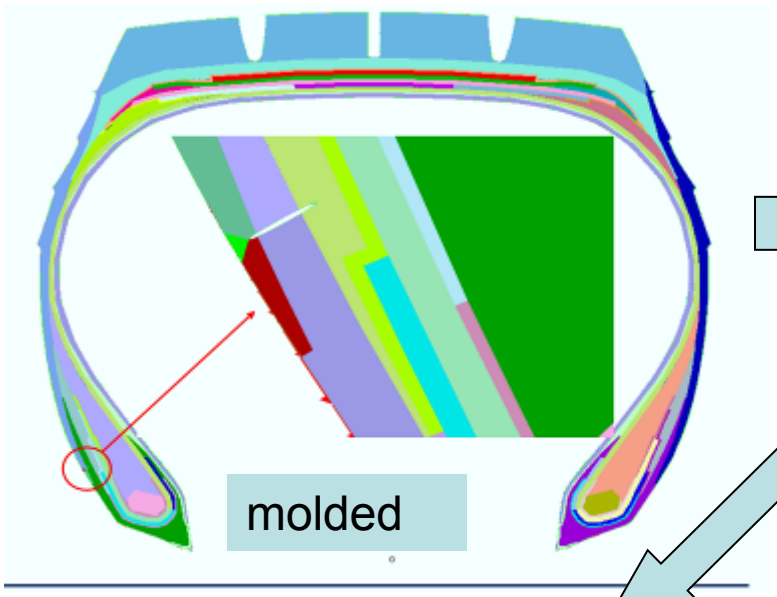
> Prototype tires made for chosen design candidates geometries

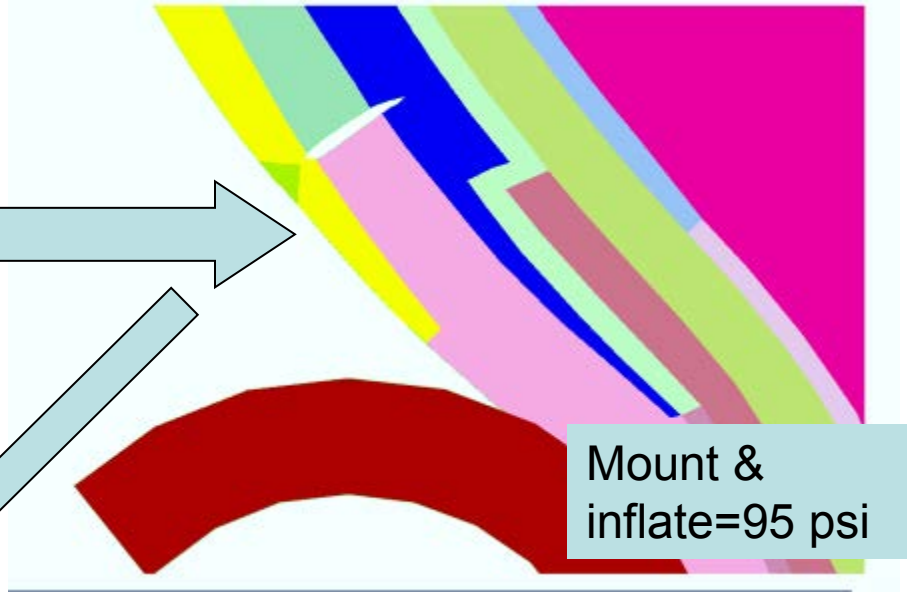
> Systems assembled and tested to evaluate performance against targets

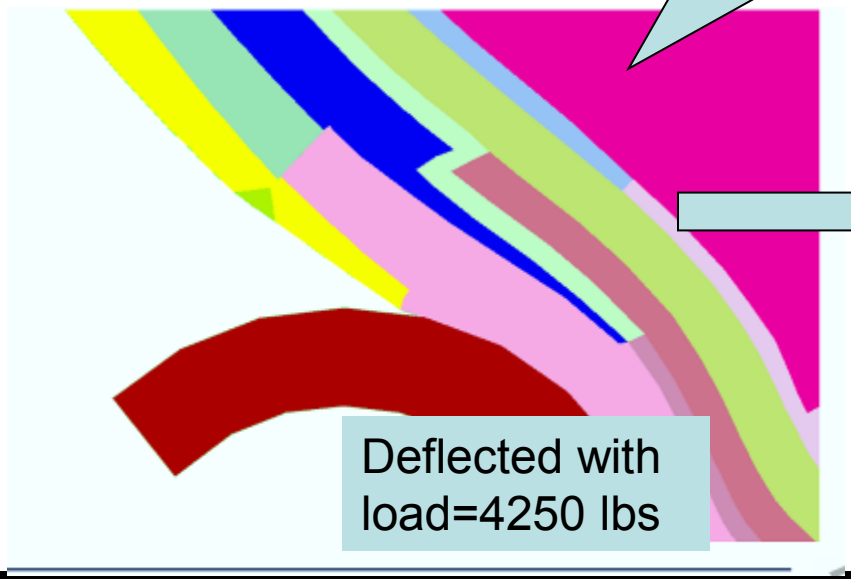
> Design iteratively refined

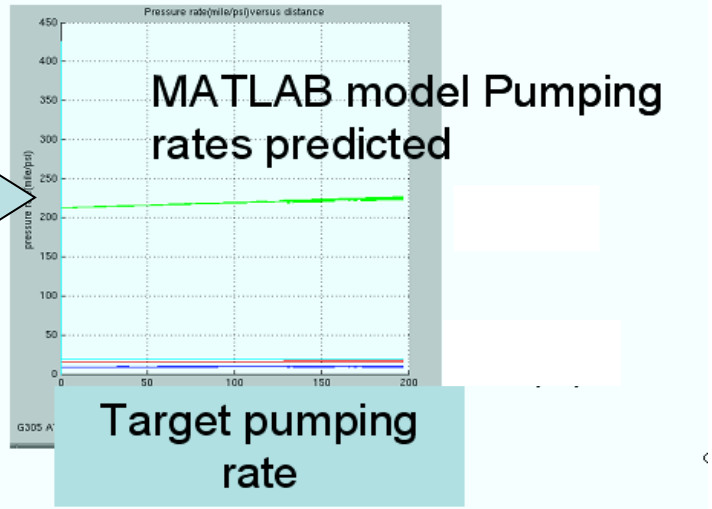
Approach: Simulation process for design

FEA tire deformation models used to drive Matlab thermodynamic models









Approach: Component Development Methodology

Product specification drives regulator and filter specifications

> Acquire initial suppliers pool

> Acquire initial prototypes

> Evaluate prototypes in laboratory

Select a development partner

> Acquire components

> Tabletop test in laboratory

Assemble system tires

> Test on road wheel and flat track

> Test on vehicles

Evaluate performance against targets

Iteratively refine design

Load and spin tire in lab to test pumping performance

> Monitor tire pressure and temperature continuously

> Evaluate
- Pump pressure
- Pump flow rate (back calculation)
- Regulator function

> Test over range of typical service loads, speeds, torque and slips

New (Goodyear) tests defined by product performance requirements

Typically many short tests (90 minutes)

Challenges
> Long term durability
> Survival through retreading process

Plan includes extended over-the-road truck fleet testing to evaluate system performance

> Multiple tire positions will be tested

> Tires will be retreaded and returned to service during trial

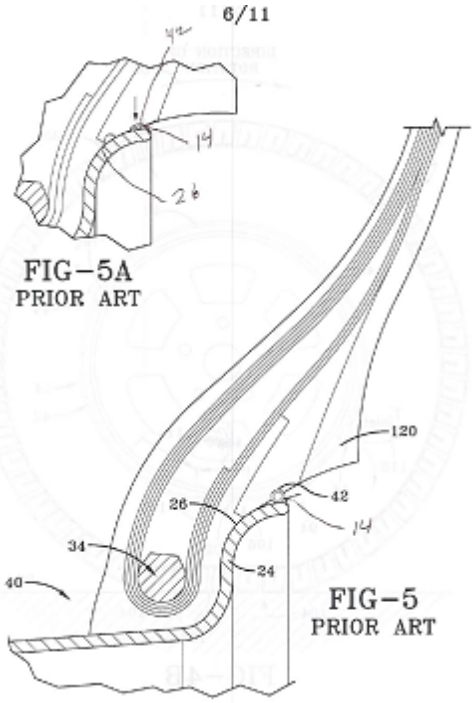
> Truck tire pressures will be tracked and compared to control group

Fuel economy will be estimated by pressure dependent models

> Specific models generated by SAE test protocols

Prior Art:

- Unidirectional pump
- Tube pinched by rim crush



FIG–5A
PRIOR ART

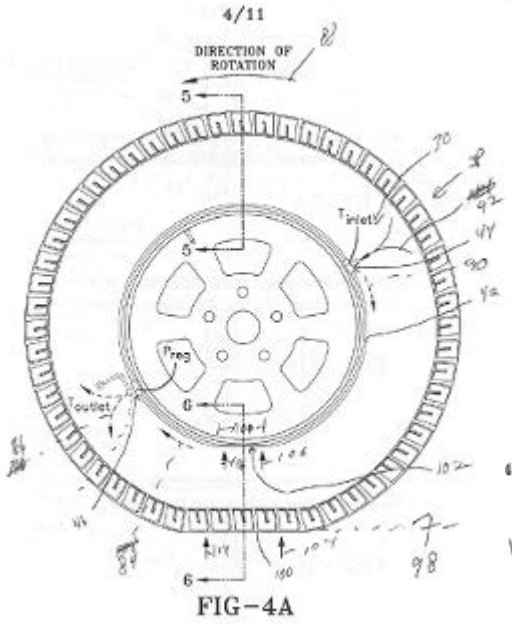
FIG–5
PRIOR ART

- Limited motion available
- Sensitive to rim variations

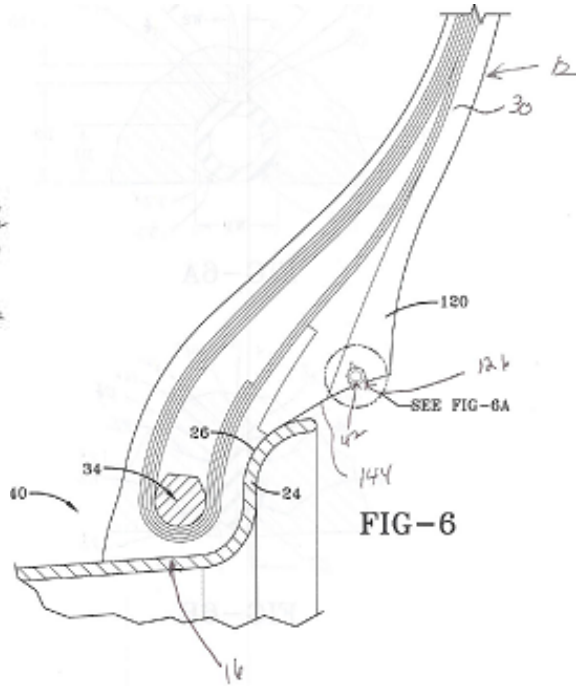
New Art:

- Bi-directional pump
- Tube pinched by bending

Patents: 8113254 8042586



FIG–4A



FIG–6

- Bi-directional pumping
- Self cleaning filter

- Larger motion available
- Tolerates rim variations

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 demounting

Regulator

> Weight Limits: Regulator: 5 oz

> Pressure Range: 90 – 135 psi

> Regulation accuracy: 2 psi

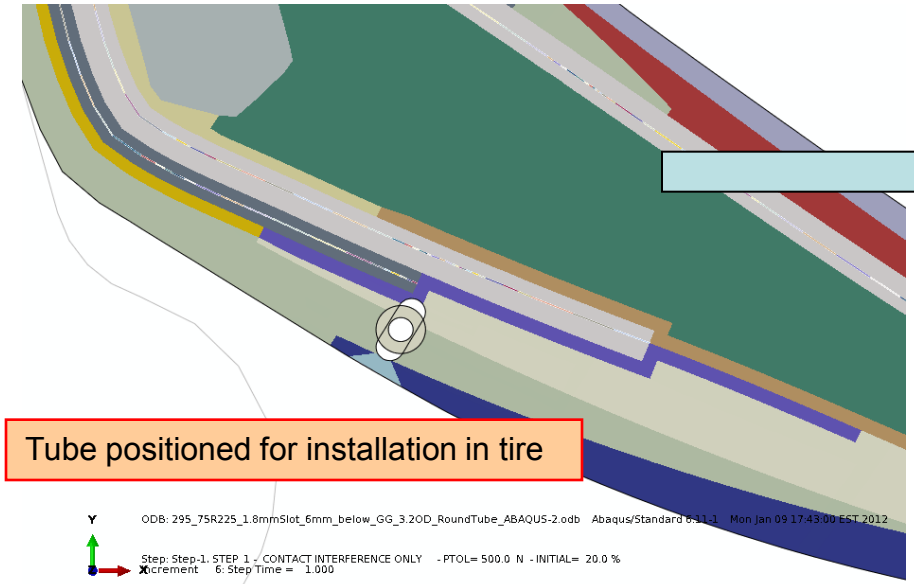
Filter

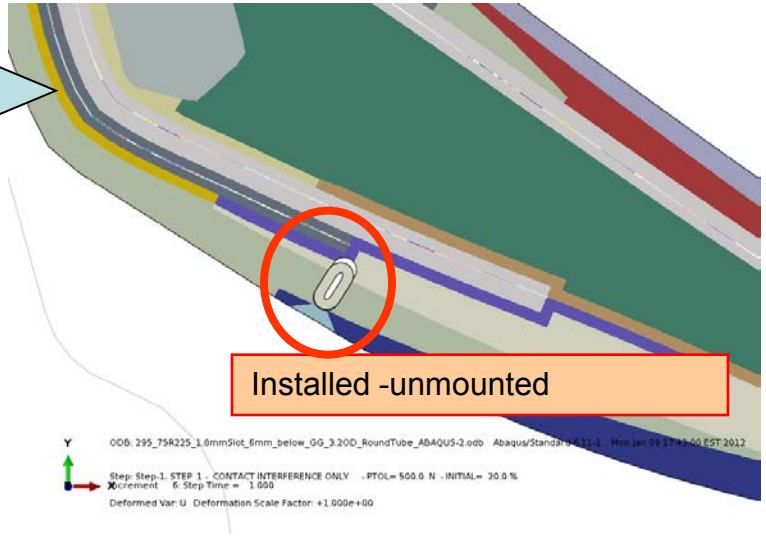
> Weight limit: 3 oz

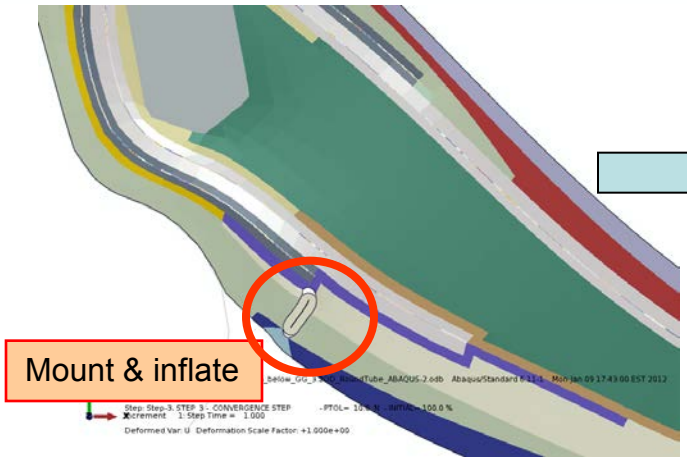
> Prohibits liquid and particle entry

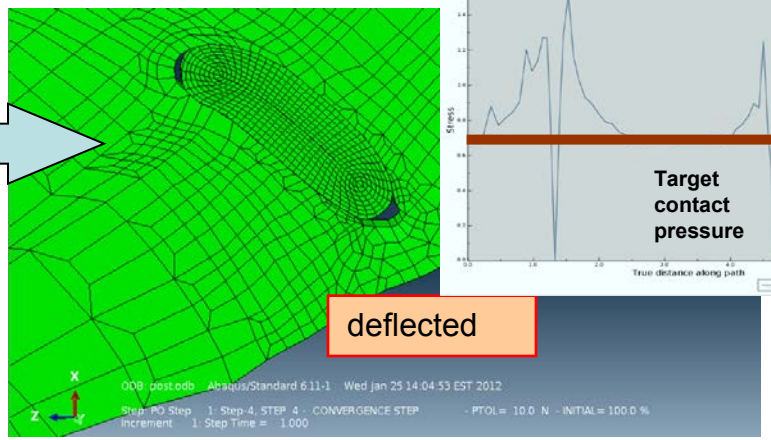
Technical Accomplishments & Progress: Design evaluation by modeling

FEA tire deformation analysis used for pump design, initial models and design completed









Preliminary testing

> Two tire air passage concepts passed initial durability tests

> Grooved tire passed initial durability tests

Initial pump design generated by simulation

> Hand carved prototype made

- Tires tested for durability, pump integration

> Tire mold features machined to initial design

> First tire plant trial completed

- Tires with pump integration groove molded without problem
- Tires arrived in Akron 12-March
- After inspection, basic pumping tests are planned

Collaboration & Coordination

Product requirements and environment

> Discussions with truck fleet representatives to develop system performance requirements
  - With fleets, Goodyear customer service engineers and Goodyear fleet maintenance product suppliers

> Visits to tire retreading facilities to develop service conditions

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

Three (3) vendor/supplier contracts currently under way; Sam Landers, AMB and Logan

> 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
  - Activities planned at Logan Machine Company's manufacturing facility will include fabrication support for test jigs, fixtures, molds and prototype parts

Collaboration & Coordination: Component Suppliers

Air management components to be provided by suppliers

> Regulator, filter, check valves

> No specific expertise or manufacturing capability at Goodyear

Initial component specifications developed

Supplier evaluation matrix developed

Strong preference to source regulator and filter from same supplier

> Filter specification depends heavily on regulator requirements

RFQ issued to 29 companies

> Seven Responses: four negative, three positive

Three suppliers will provide initial prototypes for evaluation

Plan to select single supplier for development collaboration

Proposed Future Work - 2012

Additional development build iterations in Topeka, Kansas manufacturing facility (295/75R22.5 G305 AT): 22-June and 05-October ship dates

Build Objectives;

> Cover strip process test
> First pump trial
> Evaluate green-to-cure mapping
> Process trial: design – rings – building

Continue to define and refine system, component and process specifications

> Proposed design (including process)
> Component specs
> DFMEA / PFMEA

Preliminary cost estimate (majority to come from components)

Build Prototype tire that pumps (3Q) – may be into external chamber

> Demonstrate pumping capabilities

Build Prototype tire that pumps and regulates (4Q)

> Demonstrate system capabilities
> Spec'd and procured regulator

Vehicle validation to commence October 2013

Awards / Interest

Unsolicited awards Goodyear has received for its AMT project

> Car & Driver

Goodyear's Air Maintenance Technology (AMT) has been selected by Car & Driver magazine as one of "ten most promising future technologies" in its 2012 10 Best edition.

> Auto Sports magazine - Publication in China

In their annual awards, *Auto Sport Magazine*, one of China's leading auto publications, declared AMT "Best Technology of the Year." "Creating tires that can maintain inflation automatically is a challenging mission, but Goodyear has achieved this. This technology will not only make driving safer, but also reduce fuel consumption." said Mang Chao, the editor of *Auto Sport*.

Goodyear was also nominated for Tire Technology of the Year by Tire Technology International Magazine.

Since the press release announcing Goodyear's project, issued in August 2011, Goodyear has received more than 50 stories

> Many in large consumer facing media outlets (USA Today, Wall Street Journal, NY Times, CNN, major tech blogs, etc).

Summary

- ☑ Team formed, facilities and operations organized, plan updated
- ☑ Target tire selected for development
- ☑ Initial product and component specification developed
- ☑ 2 US Patents Issued, 23 filed, 50+ in process
- ☑ First passage durability tests completed successfully
- ☑ First sidewall groove durability tests completed successfully
- ☑ Initial modeling completed, initial design developed
- ☑ Tire mold feature machined for initial design
- ☑ First plant build of initial design prototype tires
- ☑ RFP issued to suppliers, responses received, selection in progress
- ☑ Specialized test equipment procured
- ☑ Project on track

(Summary items as of 16-March-2012)

Technical Back-Up Slides

Technical Back-Up Slide: Approach: Tire System Durability Testing

Tires will meet

> DOT mandated tests (FMVSS)

> Internal Goodyear test grid for tire release

Standard tire lab tests

> High load

> High cycle

> Temperature extremes

New tests for AMT features

> Pump performance and durability

> Environmental exposures

> Regulator accuracy