Final Scientific and Technical Information (STI) Report for DOE/EERE

Project Title:	"A System for Automatically Maintaining Pressure in a Commercial Truck Tire"
Project Period:	October 1, 2011 to September 30, 2016
Recipient:	The Goodyear Tire and Rubber Company 200 Innovation Way Akron, OH 44316-0001
Award Number:	DE-EE0005447
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Executive Summary (Background):

Under-inflated tires significantly reduce a vehicle's fuel efficiency by increasing rolling resistance (drag force). The Air Maintenance Technology ("AMT") 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. The system consists of an inlet air filter, an air pump driven by tire deformation during rotation, and a pressure regulating device.

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

The work was divided into three phases. The objectives of Phase 1, Planning and Initial Design, resulted in an effective project plan and to create a baseline design. The objectives for Phase 2, Design and Process Optimization, were: to identify finalized design for the pump, regulator and filter components; identify a process to build prototype tires; assemble prototype tires; test prototype tires and document results. The objectives of Phase 3, Design Release and Industrialization, were to finalize system tire assembly, perform release testing and industrialize the assembly process.

Goals and Objectives vs. Actual Accomplishments

Despite some significant delays to the success of Phase 2, all of the goals and objectives of this project were achieved. These included the following major goals.

- Increase overall commercial fleet fuel efficiency
- Improve tire wear and service life
- Decrease fleet tire maintenance costs and compliance with federal safety regulations

The following page illustrates the milestone log over the course of the project.

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 (a)	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 latest iteration of Eaton regulator/filter components (b)	41	24-Feb-15
Milestone	**Phase 3: Design Validation**	**Month**	**Date**
M16	Delivery of control valve components begins for fleet testing assembly (b, c, d)	49	15-Oct-15
M17	Assembly of fleet evaluation tires commences (e)	52	1-Jan-16
M18	Qualification testing completed prior to fleet (customer) evaluation	52	15-Jan-16
M19	Go/No godecision for fleet trial based on qualification testing	52	18-Jan-16
M20	Fleet evaluation tire shipments begin (f)	53	1-Feb-16
M21	DOE project completed. Approximately 5 months fleet evaluation completed	60	30-Sep-16

(a) Check valve test - non-functioning regulator. Continuous test. Tires with functioning regulators will be deployed (see M15)
(b) Functioning regulators / control valves
(c) Goodyear Akron / San Angelo qualification testing, ~13 weeks, leading to M19 (Go/No go)
(d) Approx. 50 / month (delivery to begin prior to M19 to be ready for fleet trial - some risk involved)
(e) Approx. 15 / week (assembly to begin prior to M19 to be ready for fleet trial - some risk involved)
(f) 1st group of tires to be assembled and ready to ship per M19 decision. Deployment to accounts Feb 2016 - May 2016. Expected duration 18 mos.
Note; If M19 decision is a 'No go', additional iterations would be needed. Additional iterations could consume an additional 7-17 weeks (1.5-4.0 mos)

Summary of Project Activities

What follows is summary of the major activities completed during this project by government Fiscal Year (Oct 1-Sept 30).

FY 2012:

Overall

- Completed tube compression tests under different air flow pressure and ending conditions.
- Prepared a truck tire with 16 passages (2 sizes, 4 locations above and below the GG Grooves, with and without steel tube insert) and shipped for non-destructive testing.
- Completed preliminary tests to grind a slot in the side of a scrap medium radial truck tire.
- Tested groove cutting using an un-inflated scrap tire. This testing proved that this method is effective for producing smooth grooves. Grooved one side of one tire with the existing tool. Then modified the tool in an attempt to make a more "teardrop" shaped groove. Further testing was carried out with this modified tool.
- Ordered groove cover strip material for trials. The cover strip was applied with gear pump.
- Prepared functional requirements for a test stand.
- Obtained the geometry & the existing Finite Element model for the selected development tire. The initial objective of this step was to validate the model with the experimental spring-rate & bead durability results.
- Completed a preliminary assessment on the available kinematic motion for a tubed type solution.
- Completed an initial review of static tests.
- Reviewed fleet data from SmarTire program.
- Proposed definition of and rationale for conditions of lower limit of pumping.
- Compiled pros/cons of inside and outside mount locations of regulator; team decision to mount inside and develop an outside mount.
- After analysis, team agreed on "working hypothesis" that regulator will be placed on the liner in the cavity.
- Developed a regulator and filter spec.
- Design of Experiments: 4 locations, metal (conducting) and plastic (insulating) passage tubes.
- Groove design recommendation developed by FEA analysis.
- Initial System specification and component specifications were developed, achieving Milestone 2

- Design review completed, Design Failure Mode Effects Analysis (DFMEA) initiated, carried out,
- The Initial simulation and modeling of the AMT completed, Milestone 3.
- Additional prototype built.
- Improvements in overall AMT system were developed, allowing for successful pumping at targeted lower loads.
- A design evaluation was completed with a demonstration of acceptable pumping performance.
- The competitive bid process for regulator and filter suppliers was completed. Vendors were selected for both.
- The competitive bid process for optimized pump tube supplier was started.
- The effect of tire service history on pump performance was evaluated.
- A more accurate pump thermodynamic model that includes partial pinch effects was developed.
- A system tire was assembled.

Pump

- Analyzed three possible pump locations
- Evaluated design ideas for the pump tube insertion station.
- A tire deformation Finite Element Analysis (FEA) model was developed.
- The initial pump geometry was developed using modeling.
- A mold ring design was developed to produce the target geometry. A mold ring was produced according to that design and prototype tires were built in a Goodyear plant.
- Laboratory scale tests were used to develop surface cleaning procedures, adhesive selection and adhesive application procedures.
- Initial assembly procedures were developed for both adhesive based and rubber cured on cover approaches.
- The apparatus to be used to measure tire pumping performance was designed, parts were procured and the device was assembled. Data logging procedures were developed.
- Tire pumping performance road wheel test procedures were developed.
- Several standard tire durability tests were used to access the durability of a prototype tire with a molded in pump tube slot. Initial test results show acceptable performance.
- A tire deformation Finite Element Analysis (FEA) model was developed.
- The first pump was assembled into a prototype tire, the tire was tested on a road wheel (e.g. Laboratory) and pumping performance was evaluated.

- Several standard tire durability tests were used to access the durability of a prototype tire with a molded in pump tube slot. Initial test results showed acceptable performance.
- The first internal design evaluation was completed with a demonstration of acceptable performance.
- Tire groove geometry was refined using measured tire geometries and pump performance.
- New mold rings were produced to reflect the refined geometry.
- Prototype tires were built using the refined design mold rings at the Goodyear plant in Topeka, KS.
- Process changes were evaluated in the prototype build to study the effects of increased heat history on tire geometry.

Components

- RFPs were developed from Goodyear's component specifications and were sent to 29 potential suppliers. Four negative responses and three positive responses were received from potential suppliers. Goodyear negotiated with these potential suppliers to determine a final vendor for prototype components.
- A series of meetings with each supplier were conducted. Questions were answered on the specifications and completed design concept reviews. Goodyear received evaluation prototypes from two suppliers, completed laboratory evaluation of their performance, and supplied results to these suppliers.
- Regulator and filter suppliers were selected after a competitive bid process.
- In order to improve pump performance, it was decided to move from off the shelf tubing to custom engineered pump tubes.
  - The competitive bid process for an optimized pump tube supplier was started.
  - RFQs were developed and distributed to four suppliers.
  - One supplier declined, the process continued with the remaining three.

Passage

- Goodyear completed the first prototype build in Topeka, Kansas. Testing of these prototypes included, but was not limited to; bead durability, rolling resistance, cover strip trials and pumping test into a chamber.
- Prototype tires with multiple passage locations, sizes and materials passed standard tire durability testing.
- Recapping process Non-Destructive Test (NDT) was exercised on prototype tires with multiple passage designs and materials. In all cases the NDT did not produce any detectable effect.
- Passages were designed based on modeling and testing results.
- Passages that realize the design were produced.
- No problems with passage durability were observed.

Modeling

- Goodyear's modeling work calculated the rolling resistance for both the control tire as well as the groove tire designed for peristaltic pumping.
- Test suite results over a range of loads and speeds exhibited more complex relations than originally assumed.
- A more accurate pump thermodynamic model was developed that includes partial pinch effects.
- The new model was implemented in MATLAB software and validated against collected test results.

System

- The first partial system tire was assembled. Included in this prototype was the pump, passages, filter holder (without filter media), and a nonfunctioning regulator that re-circulated the pumped air.
- The initial system tire assemblies exhibited poor performance at component connections.
- System tires with refined connection technology were tested.

Process

- Chemical cure and thermal cure cover strip materials were used to make prototype tires.
- Chemical cure cover strip materials were used to secure pump tubes in the grooves of prototype tires and the tires were tested for durability.
  - Long term durability was found to be poor.
- Thermal cure cover strip materials were used to secure pump tubes in the grooves of the prototype tires and the tires were tested for durability.
  - Long term durability was found to be good.
- The process used for initial thermal cure trials uses retread cure equipment and was unwieldy.
  - A new prototype process was developed that models a possible production process.
  - A fixture for testing the new process was designed and constructed.

FY 2013:

Overall

- The first system tire was tested, pressure data indicated that pumping was achieved
- A joint development agreement was completed with the selected regulator and filter supplier and the design process was initiated
- With some basic design goals accomplished, several items around ensuring long term durability were addressed:

  - Effect of tire service history on pump performance was evaluated, tire groove design changes for long term performance were initiated
  - Possible long term service effects on the pump tube, including abrasion and compression set, were addressed

- System tire tests revealed that at moderate loads, the maximum pressure and pumping rate well exceed design targets. This allows design tradeoffs to enhance low load performance at the expense of pumping rate.
- More comprehensive durability testing has been accomplished including high mileage road wheel testing.
- System and component specifications were updated to reflect latest design revisions.
- Test definitions for supplier testing of components was refined for the regulator and filter and initiated for the connectors.
- An additive manufacturer capable of printing more durable glass filled nylon was identified and prototype filter housings and regulator docks obtained for development testing.
- More comprehensive durability testing has been accomplished including high mileage road wheel testing.
- A system tire was assembled and pumping performance was evaluated on road wheels and on a vehicle.
- The regulator design was refined to decrease its size and weight.
- A second generation prototype production process was developed.

Pump

- Pumping performance was evaluated over a range of loads, tire pressures and speeds
- Measured tire geometries and pump performance after longer term testing were used to refine tire groove geometry for long term performance
- New mold rings were produced to reflect the refined geometry

- Prototype tires were built using the refined design mold rings at a Goodyear plant.
- Evaluation of prototype tires from the latest build in Topeka in system tests revealed very good maximum pressure and pumping rates at moderate to high loads. This allows design tradeoffs to enhance low load performance at the expense of the pumping rate which will be incorporated in the next build.
- Evaluation of the design did not yield consistent performance improvements. This led to increased attention to prototype building process refinements to obtain consistent high performance results.
- Road wheel and on vehicle testing both showed good pumping performance.

System

- A system tire with refined connection technology demonstrated pumping

- System tire tests revealed that at moderate loads, the maximum pressure and pumping rate well exceed design targets. This allowed design tradeoffs to enhance low load performance at the expense of pumping rate.
- A series of tests with passages only followed by passages and regulator docks verified that portion of the subsystem assembly was robust.

A system tire with pump, passages and a simple check valve was assembled and pumping performance demonstrated good pumping performance in both road wheel and on vehicle tests.

Components

- A joint development agreement was completed with the selected regulator and filter supplier and the design process was initiated, proposals were reviewed before committing to soft tooling.
- In order to improve pump performance, it was decided to move from off the shelf tubing to custom engineered pump tubes
  - Pump tube characterization tests were developed and applied to available tubing samples to aid development of specifications and selection of pump tubes
  - A competitive bid process for an optimized pump tube supplier was commenced
- Pump tube
  - Based on our work to date, eight candidate passage tube elastomer compounds were developed. A material test study of the eight candidate materials was initiated to determine the best material for passage tubes.
- Connectors
  - Prototypes of pump tube to passage tube connectors of the design proposed for production were obtained along with a tool for installing the connectors.
- Regulator
  - Regulator design was refined to decrease size and weight.
- Regulator attachment
  - Opportunities in high speed testing were solved by a redesign of the dock attachment to better distribute the regulator load and a redesign the regulator to decrease its load on the dock.
- Passage
  - Four candidate passage tube elastomer compounds were developed. A material test study of the four candidate materials was initiated to determine the best material for passage tubes
- Filter
  - A filter housing of sufficient size to allow air flow for good pumping performance is a large, rigid inclusion in an elastomeric tire.
  - A mold was designed and produced to mold filter collars. A test tire was assembled with a filter holder and collar cured on. That prototype was then sectioned to evaluate the process.

.Modeling

- Tire deformation modeling was used to refine the design of the pump tube slot to continue to tune for best performance.
- Modeling of the cure platen profile was initiated to develop a profile with a more even contact pressure in order to obtain more consistent cover strip cure results.
- Modeling of the cure platen profile for the second generation process was completed and a cure platen machined to the developed profile.
- Modeling of the regulator attachment load during high speed testing was developed and used to modify the regulator dock attachment for improved retention.

Process

- Chemical cure and thermal cure cover strip materials were used to make prototype tires
- Chemical cure cover strip materials were used to secure pump tubes in grooves of prototype tires and the tires were tested for durability
- Thermal cure cover strip materials were used to secure pump tubes in grooves of prototype tires and the tires were tested for durability
- The process used for initial thermal cure trials used existing tire retread cure equipment and was unwieldy.
    - A new prototype process has been developed that models a possible production process.
    - A fixture for testing the new process has been designed, produced and installed.
    - A prototype production process using the fixture has been developed.
    - That fixture was made and was in use in producing prototype test tires. The procedure was refined during the course of making prototype test tires.
- The adhesion system used to attach regulators to tires was observed to exhibit previously unseen problems.
    - The adhesion technology was tested in high deformation and high speed tests.
    - Issues in high speed testing resulted in a refinement in the process which underwent evaluation.
- Manufacturing
    - Development of a second generation prototyping process was initiated with the goals of delivering better process control and larger volumes. This process will be used to produce fleet trial tires.
        - The process concept was developed and reviewed with manufacturing team members
        - CAD drawings of apparatus to support the new process were developed
        - Equipment was produced and assembled

FY 2014:

Overall

- On vehicle testing began on the Akron test track.

- A decision was made to proceed with an on vehicle trial.
- A continuously running over road vehicle trial was initiated at the San Angelo Proving Ground.
- More comprehensive durability testing was accomplished including high mileage road wheel testing - this includes tires with passages, pumps tubes, and cured on cover strips.
- An on-vehicle trial of AMT tire casings was carried out.
- An over-road vehicle trial continued, based from the San Angelo Texas Proving Ground. A truck running 1150 miles a day, 5 days a week accumulated 5750 highway miles each week.
- High deformation testing was carried out to gauge wear and other durability characteristics of pump and passage tube materials with a goal of final material selection for the on-vehicle fleet trial.
- The tire design for the fleet evaluation was finalized.
- Selection of all system components for large volume fleet evaluation was completed. Procurement of system component volumes for the fleet evaluation commenced.
- An improved (second generation) manufacturing system for AMT system component installation was designed, procured, and installed. Optimization of the system processes was on-going. This system was planned be used to manufacture prototype tires for the vehicle trial.

Pump

- Road wheel and on vehicle testing have both shown adequate pumping performance over a range of loads.
- AMT system component installation and curing process has been further optimized to provide consistent pumping performance across a broad range of vehicle loads.

System

- A system tire with pump, passages and a simple check valve was assembled and pumping performance demonstrated adequate pumping performance in both road wheel and on vehicle tests.
- Several AMT system tires with pump, passages, and a simple check valve were assembled and passed required testing for use of prototypes on public roads. These tires were placed into long term over-the-road vehicle testing. The testing program monitored tire pressures in the system and control tires by recording on-board TPMS readings and with daily tire pressure checks.
- A system tire with all components including a functional regulator was assembled and tested on a road wheel. The prototype system was observed to pump up to the set pressure at which point pumping ceased.
- A system tire with a simple check valve in place of the regulator was assembled, tested for pumping performance, sent through the normal tire retread process and

then retested for performance. Results showed that the prototype still pumped but at a reduced performance. A forensic was performed to diagnose the issue.

- A removable system dock cap was designed to take the place of the regulator and permit functional pumping and evaluation of all system components minus the regulator. Replacement of the cap with a functioning regulator would have enabled a direct comparison and provide regulator performance characterization.

Components

- Passage
  - Four candidate passage tube elastomer compounds were developed. A material test study of the four candidate materials was initiated to determine the best material for passage tube long term durability. This study was completed and a material was selected for the fleet trial.
  - Passage tubes were obtained and underwent testing for release for use in the fleet evaluation.

- Pump tube
  - Eight candidate passage tube elastomer compounds were developed. A material test study of the eight candidate materials was initiated to determine the best material for pump tube long term durability. The test was completed and a material was selected for the fleet trial.
  - Pump tube acceptance criteria was defined.
- Filter
  - A mold was designed and produced to mold filter collars. Filters and collars were bonded to tires for system road wheel tests and on vehicle trials. The snap-in filter cover samples were found to have clearance issues and could not be assembled into the holder. The design was refined to improve assembly.
  - Filter housings and filter covers with revised designs that exhibit better fit were received.
  - A method to seal the filter housing to prevent ingress of unfiltered air into the AMT system was developed and verified. This was a temporary solution that had been used with San Angelo truck testing and if necessary, could be used in the larger volume fleet trial.
- Connectors
  - Prototypes of pump tube to passage tube connectors of the design proposed for production were obtained along with a tool for installing the connectors.
  - Assembly of the connectors was found to be difficult. Estimates of connector costs were also found to be well above expected. For these reasons the proposed connector design was dropped in favor of the technology used in prototyping.
  - Connector design was optimized for performance and mold feature pockets created to house these connectors in cured tires.
- Regulator and dock
  - Regulator design was refined to decrease size and weight.

  - Regulator prototypes of the revised design were received and lab bench tested. This led to several rounds of assembly process refinement to reach regulator performance specifications.
  - Lab bench testing was used to select a regulator for system tire testing that was previously mentioned.
  - Additional iterations of regulators were received and bench tested.
  - Goodyear created a new functional performance specification to simplify the bench testing procedure for regulator acceptance criteria.

- Regulator attachment
  - Redesigned docks with overmolding were received and tires containing the new docks underwent high speed tire testing.
  - Regulator to dock attachment issues were revealed in high speed testing
  - The regulator to dock attachment was redesigned and new prototypes were created.
  - Design modifications were proposed.

Modeling

- Modeling of air flow in the pump system was refined.
- Modeling of on vehicle system performance using typical service conditions was initiated.
- Modeling of air flow in the pump system was refined to include load, speed, and tire cavity inflation effects.
- Modeling of on-vehicle system performance using typical service conditions was exercised on several pump rate scenarios.

Process

- Manufacturing
  - Development of a second generation prototyping process was initiated with the goals of delivering better process control and larger volumes. This process will be used to produce fleet trial tires.
    - The process concept was developed and reviewed with manufacturing team members
    - CAD drawings of apparatus to support the new process were developed
    - Equipment was produced and assembled
    - First trials were completed indicating a need to modify the process
    - The modified process will be tested in the next period
    - Equipment was installed and process optimization proceeded.
    - Initial tires cured with the second generation process were built.
    - A new and simplified clamp was designed to secure the regulator dock for curing.

Fleet Evaluation

- The fleet evaluation plan was defined to include several fleets and a range of service conditions.
- In service tire monitoring procedures were defined.

FY 2015:

Overall

- Over road trials were carried out. Various combinations of AMT tires, from as-molded without system components to system pumping tires, were placed on the truck before the full system tires with functioning regulators became available.
- The tire design for the fleet evaluation was finalized
- System component selection for the large volume fleet evaluation was completed
- An improved (second generation) manufacturing system for AMT system component installation was designed, procured, and installed. This system was used to manufacture prototype tires for the fleet evaluation
- The AMT manufacturing process and system installation equipment was relocated, installed, and was fully functional
- Process optimization efforts are ongoing
- The regulator docks are not of the latest design iteration, but the decision was made to go forward and begin on vehicle testing in order to gain experience with the regulators
- Full system tires will be available for placement on the truck by mid-November.

Components

- Pump
  - AMT system component installation and curing process was further optimized to provide consistent pumping performance across a broad range of vehicle loads
  - Pumping variation and repeatability trails were conducted in an effort to understand process variations and rim and mounting potential effects.
- System
  - A removable system dock cap was built to take the place of the regulator and permit functional pumping (minus regulation). This cap was debugged and optimized. Replacement of the cap with a functioning regulator will enable a direct comparison and provide regulator performance characterization.
- Passage
  - Passage tubes were obtained and underwent testing for release to use in the fleet evaluation
  - Modelling was done to understand the effect that material modules have on pumping performance
  - Passage tube modelling has been done to understand the effect that material modulus has on pumping performance.

- Pump tube
  - Acceptance criteria for pump tubes were defined
  - Pump tube to passage tube connections continue to be critically evaluated for robustness after a number of leaking connections were identified in tires designated for dynamometer testing
  - Bench tests were developed to evaluate connection integrity without the need to assemble into a full AMT system tire.
- Filter
  - Various methods to retain the filter housing in the tire during operation were developed by the vendor and have been evaluated in lab testing. This was a temporary solution that can been be used with both the truck testing and if necessary, in the larger volume fleet trial
  - The performance of the temporary solution to affix the filter was acceptable. A permanent solution for filter attachment has not been tested or implemented.
- Regulator & Dock
  - Iterations of regulators were received and bench tested
  - Goodyear created a new functional performance specification to simplify the bench testing procedure for regulator acceptance criteria
  - A joint workshop was held to identify opportunities and plans to improve the regulator functionality. A reduced performance specification for the regulator was agreed to temporarily in Q1 of FY15 in order to expedite the delivery of some quantity of regulators to advance testing of the regulator in full assembly in the tire
  - The temporary reduction of performance specification for the regulators agreed to in the December workshop allowed delivery of twenty functioning regulators in February/March. Bench testing discrepancies led to plans to upgrade the Goodyear test system as well as documentation on test procedures
  - Air leakage was also found between the dock and the regulator leading to a partial fix. A workshop was held to address the problem of air leakage between the dock and the regulator
  - The result of the workshop (via PUGH matrix analysis) was an agreement to redesign the dock with regulator design unchanged. In the current design, where the sealing mechanism is integral (over-molded) to the dock, the loss or lack of sealing necessitated scrapping the AMT tire. In the new design, the dock to regulator interface will now utilize a replaceable sealing mechanism that will enable replacement of this part if sealing is inadequate or compromised. A replaceable seal also provides the ability to evaluate multiple seal designs or materials more efficiently. This dock design iteration has not yet been implemented or tested. Delivery of small lots of new docks, seals, and regulators is targeted for 10/07/2015.
- Regulator attachment
  - Dock design changes were implemented and will continue to be incorporated. This resolved high speed attachment issues

Further dock design changes were identified to improve high speed attachment and wear issues. This requires dock over-mold tooling modifications.

Process

- Manufacturing
  - Development and optimization of a second generation assembly process continues with the goals of delivering better process control and larger volumes. This process will be used to produce fleet trial tires
- The quick pump system test for QC check of full system tires was proven to perform successfully.

Fleet Evaluation

- The fleet evaluation plan was defined to include several fleets and a range of service conditions
- In service tire monitoring procedures were defined
- Fleet evaluation will not be initiated until successful vehicle evaluation on the Goodyear tractor trailer has been confirmed.

FY 2016:

Overall

- The AMT manufacturing and testing processes continued to be refined and the team focused on product, process, and people-readiness for the assembly and testing of our Lab, and Customer Focus Tires
- Goodyear placed the internal regulator iteration of this project on hold in January 2016 and moved forward with a valve stem method/iteration of this project instead
- Goodyear focused on product testing, process, assembling AMT products for customer vehicle testing, and AMT product industrialization
- Goodyear proceeded successfully into on-vehicle testing to date with the following milestones
  - 16 AMT tires are in operation at Goodyear's testing facility on two trucks, along with 8 control tires.
  - Over 3 million miles of AMT tire durability evaluation
- Focus account testing (customer vehicles)
  - 24 AMT tires, w/TPMS Systems for monitoring, installed Feb 11-13, 2016
  - 24 Control tires, w/TPMS Systems, installed March 3, 2016
- All test facility and customer vehicles have Tire Pressure Monitoring Systems installed allowing engineers to track vehicle location, tire pressure, and temperature
- Goodyear continues to monitor the performance of the AMT tires and contrasts with the performance of the control tires.

Components

- Pump Tube

  - The team continues to work with our pump tube supplier, to meet pump tube specifications. Current discussion have been on tolerances and pump tube cost. The team is working with the suppler on options to reduce the pump tube component cost.

- Filter
  - Experienced separation of the rubber over-molded filter dock and peristaltic pump tube cover strip, during wheel testing.
  - System tires were assembled and placed in durability testing to test adhesion.
- Regulator and Dock
  - Significant improvements were made to the docks and regulators. Docks were proven and tested with rubber removable seals, which went on to be used for System Tire Assembly. All components, include tire peristaltic pumping system performed well in static conditions. However, when assembled, and tested in a dynamic condition on a road wheel, the system of components failed to meet expectations.
- Regulator Attachment
  - New iteration docks were delivered by supplier which had curved base to improve high speed attachment and wear issues. New dock clamps were manufactured to support curved docks. Goodyear developed a new passage connector insert process for removable seal docks.
- Control Valve Interconnections
  - The valve stem product contains (2) interconnect tubes which Goodyear optimized for quality and performance of the tubes, and their fittings
- Process
  - The quick pump system test for QC check of full system tires was proven to perform successfully. Goodyear developed an end of line test on the AMT Assembly cell to check for pump tube flow and for leaks prior to the quick pump QC check
  - Goodyear focused on improving the AMT Assembly process in our Proof-of-Concept AMT Cell:
  - Improvements to the dome and pump tube fitting assembly process
  - Improvements made to the dome pre-molding process to eliminate lights in the cured AMT Product
  - Reducing cure time study – curing tires at higher cure temperatures, at a reduced cure time
  - Team is analyzing the dome area for total amount of cure
  - Control valve test stand –Goodyear has a quantity of (2) test stands to validate AMT control valves for testing. All control valves are validated over the operating pressure ranges, and efficiencies calculated.
- AMT Product Industrialization
  - The team continued to focus on the industrialization of the AMT product
  - Establishing product and process specifications
  - Product cost analysis

- Facility Specifications
- Process requirements based upon projected demand
- Operational expense
- Working with a facilities planning consultant engineer
- Developing an overall process and product cost model
- Working with the marketing team for gate process and develop the business case.

Fleet Evaluation Results:

- Tires operating on 3 different customer fleets in North America
- Various ambient temperature ranges: Cold to hot regions
- Mileage ranges from 15,000 to 105,000 miles
- 72 AMT tires and 72 control (non AMT) tires
- Real time TPMS data being monitored from each tire
- AMT tires maintaining their set inflation pressures, pressure loss is 0 PSI per month
- Control tires losing an average of 2.5 PSI per month
- Overall, AMT tires are performing as expected in various real world conditions

Publications/Presentations:

- 2012 Vehicle Technologies Office Annual Merit Review Presentation
- 2013 Vehicle Technologies Office Annual Merit Review Presentation
- 2014 Vehicle Technologies Office Annual Merit Review Presentation
- 2016 Vehicle Technologies Office Annual Merit Review Presentation

Patents

1st Patent 8,042,586 - Issued 25-Oct-2011
Abstract: A self-inflating tire assembly includes an air tube mounted within a tire sidewall groove. The air tube is in contacting engagement with opposite angled groove surfaces surrounding the air tube. A segment of the air tube is flattened from an expanded diameter to a flat diameter by bending and compression of the groove in a rolling tire footprint to force air evacuated from the flattened segment along a tube air passageway. The sidewall groove extends into an annular, axially extending, sidewall surface such as an axially oriented surface of a tire chafer protrusion located in non-contacting relationship with the rim.

2nd Patent 8,113,254 - Issued 14-Feb-2012
Abstract: a self-inflating tire assembly includes an annular air tube connected to a tire and defining an annular air passageway, the air tube being composed of a flexible material operative to allow an air tube segment opposite a tire footprint to flatten, closing the passageway, and resiliently un-flatten into an original configuration. The air tube is sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air along the passageway to an inlet device for exhaust from the passageway or to an outlet device for direction into the tire cavity. The inlet device is positioned within the annular passageway 180 degrees opposite the outlet device such that sequential flattening of the air tube by the tire footprint effects pumping of air along the air passageway with the tire rotating in either a forward or reverse direction of rotation.

3rd Patent 8,156,978 - Issued 17-Apr-2012
Abstract: An air passageway body resides within a tire body and extends between an outward facing tire body surface and the tire cavity, the air passageway body having an enclosed air passageway extending between a hollow body outlet end facing the tire cavity and a hollow inlet end facing outward from the outward facing tire body surface. A tapping device is affixed over one or both of the ends of the air passageway body, the tapping device having an external vent opening and a protrusion member penetrating through a sidewall of the air passageway body to operatively establish an air flow path extending between the air passageway of the air passageway body through the protrusion member and the tapping device vent opening. The air passageway body is installed pre-cure within a green tire carcass build of the tire body and the tapping device(s) are attached post-cure to the air passageway body.

4th Patent 8,235,081 - Issued 07-Aug-2012
Abstract: A tire for a self-inflating tire system includes a tire carcass having an annular air tube-receiving groove formed within a tire carcass wall and a pump assembly within the

groove. The pump assembly includes an air tube having an axial air passageway; an inlet device positioned along the air tube, the inlet having a tubular inlet body having an internal air passageway aligned with the air tube and having at least one inlet opening extending through the inlet body for admitting air into the tubular inlet body. The inlet device further includes an air filtering sleeve at least partially surrounding the inlet opening of the inlet device, the sleeve having a tubular sleeve body at least partially surrounding and in co-axial relationship the tubular inlet body. The pump assembly further includes an outlet device positioned in-line along the air tube, the outlet device having a tubular outlet body and an axial passageway in-line with the air tube and having at least one outlet passage tube from the outlet device through the carcass wall to the tire cavity.

5th Patent 8,291,950 – Issued 23-Oct-2012
Abstract: A tire assembly includes a tire carcass body and an air tube body extending between an outward facing tire body surface and an inward tire body surface. The air tube body has an enclosed hollow enclosed outlet end at a first end and an enclosed hollow inlet end at an opposite second end. An air passageway extends through the air tube body from the inlet end to the outlet end. The outlet end is positioned to face exposed from the outward tire body surface and the inlet end is positioned to face exposed from the inward tire body surface. The air tube body is integrally formed of resilient flexible material composition and includes a hollow outer casing and one or more hollow air cables positioned within the casing for regulating the rate of air flow from the inlet end to the outlet end. The air tube body may follow a non-linear U-shaped path that surrounds a tire body bead core between the outward tire body surface and the inward tire body surface and be incorporated into the green tire build without disrupting the tire building and curing process or compromising the structural integrity or form of any of the green tire building components.

6th Patent 8,322,036 - Issued 04-Dec-2012
Abstract: A method of constructing a self-inflating tire assembly includes molding in an air tube-receiving groove within a green tire carcass wall, the groove having an access opening, primary internal groove chamber and a secondary expansion groove chamber adjacent to and communicating with the internal groove chamber. A groove partial passageway is molded with the groove at a prescribed groove outlet location and extends from the groove partially through the tire carcass wall toward the tire cavity. A tire carcass wall barrier of reduced section between the partial passageway and the tire cavity is removed in a post-cure operation to create a through-bore from the groove to the tire cavity. A pump assembly inserts into the tube-receiving groove in a post-cure procedure with an outlet passage tube from a pump assembly outlet device extended through the through-bore to the tire cavity.

7th Patent 8,381,784 – Issued 26-Feb-2013
Abstract: A groove is positioned within the bending region of the first tire sidewall and deforms segment by segment within the rolling tire footprint. An air tube positioned within the sidewall groove is in contacting engagement with groove sidewalls and resiliently squeezes and collapses segment by segment as the groove constricts segment by segment within the rolling tire footprint. A series of adjacent projecting ridges extend from a groove sidewall segment into the groove air passageway, the projecting ridges operatively positioned to vary the applied pressure on the air tube increase the air pressure within the air

tube passageway as the air tube rolls segment by segment with the tire through tire footprint. The series of projecting ridges are constructed having variable amplitude and/or spacing frequency in a direction of air flow within the air passageway to increase the pressure applied to the air tube and air pressure of the air flowing through the tube passageway.

8th Patent 8,381,785 – Issued 26-Feb-2013
Abstract: A self-inflating tire assembly includes a tire having a tire cavity between first and second sidewalls that extend respectively from first and second tire core beads to a tire tread region. At least one of the sidewalls is provided with an air tube peristaltic pump assembly. An air tube has an internal tube air passageway and is positioned within a sidewall groove in contacting engagement with opposite groove surfaces surrounding the air tube. The sidewall groove operatively bends within a rolling tire footprint to compress the air tube from an expanded diameter to a flat diameter adjacent the rolling tire footprint. A core bead passageway extends within a core bead adjacent the one tire sidewall for operatively storing air evacuated from the air tube passageway. Conduits are provided to route air from the air tube to the core bead passageway and valve mechanisms are positioned within the core bead passageway to control the flow of air from the core bead passageway into the tire cavity.

9th Patent 8,394,311 – Issued 12-Mar-2013
Abstract: A method of constructing a self-inflating tire includes: forming a pre-cure green tire body; positioning an air passageway body within the green tire body to extend between an outward facing green tire body surface and the tire cavity, the air passageway body having an enclosed air passageway extending between a hollow body outlet end facing the tire cavity and a hollow inlet end facing outward from the outward facing green tire body surface; curing the green tire body into a finished cured tire body; affixing one or more tapping device(s) over one or both ends of the air passageway body; and establishing through a hollow protrusion member of the tapping device an air flow path extending between the air passageway within the air passageway body and a vent opening within the tapping device. The method includes a routing of the air passageway body through the green tire body along a non-linear path between an outward tire body surface and the inward tire body surface; wherein the non-linear path to at least partially surround a first tire body bead core; and wherein the air passageway body is positioned between overlapping green tire components such as first and second tire turn-up chafer components.

10th Patent 8,534,335 – Issued 17-Sep-2013
Abstract: A self-inflating tire assembly includes one or more air tube(s) connected to a tire and having a plurality of adjoining diaphragm chambers separated by a one-way valve. An air passageway extends through the air tube and the diaphragm chambers. The one-way valve allows a directional passage of air through the valve from an inlet valve side an outlet valve side. The footprint in a rotating tire sequentially collapses the diaphragm chambers to directionally pump air through the one-way valve between the diaphragm chambers and along the air passageway from an air tube inlet device to an air tube outlet device.

11th Patent 8,550,137 - Issued 08-Oct-2013
Abstract: A tire for a self-inflating tire system includes an annular air tube-receiving groove formed within a tire carcass wall at a prescribed radial location. The groove has an access

opening, a primary internal groove chamber dimensioned and profiled for close receipt of an annular air-pump tube. A secondary expansion chamber of the groove communicates with the internal groove chamber for operationally receiving a flattened air-pump tube extended portion during tire operation. A passageway is located at a prescribed outlet location along the annular air tube-receiving groove, the passageway extending from the groove to an axially inward terminal end within the tire carcass wall separated from a tire inner liner by a removable wall partition of reduced sectional thickness.

12th Patent 8,573,270 - Issued 05-Nov-2013
Abstract: A self-inflating tire assembly includes an air tube connected to a tire and defining an air passageway, the air tube being composed of a flexible material operative to allow an air tube segment opposite a tire footprint to flatten, closing the passageway, and resiliently unflatten into an original configuration. The air tube is sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air along the passageway to a regulator device. The regulator device regulates the inlet air flow to the air tube and the outlet air flow to the tire cavity.

13th Patent 8,651,155 - Issued 18-Feb-2014
Abstract: An air-maintenance tire system includes a compression actuator mounted to the tire carcass configured for operative actuation by tire deformation during a tire revolution, a pump assembly affixed to the tire carcass and including a compressor body affixed to the compression actuator and having an internal air chamber, the air chamber having an inlet opening for admitting air into the internal air chamber and an outlet opening for conducting air from the internal air chamber to the tire cavity. The air compressor body further includes a piston valve member and an outlet valve member located within and at opposite respective ends of the internal air chamber, the piston valve member and the outlet valve member moving within the internal air chamber responsive to actuation by the compression actuator between respective open and closed positions, whereby cyclically opening and closing the inlet and the outlet openings during an air compression cycle. The compression actuator includes a hollow containment body formed from a resilient deformable material composition and containing a quantity of a non-compressible medium. The containment body is affixed to a relatively high flex-deformation region of the tire carcass and reciprocally transforms between a deformed state and a non-deformed state to generate a compression force against a piston valve member surface and move the piston valve between the open and closed positions within the air chamber.

14th Patent 8,656,972 - Issued 25-Feb-2014
Abstract: An air-maintenance tire system includes a compression actuator mounted to the tire carcass configured for operative actuation by tire deformation during a tire revolution, a pump assembly affixed to the tire carcass and including a compressor body affixed to the compression actuator and having an internal air chamber, the air chamber having an inlet opening for admitting air into the internal air chamber and an outlet opening for conducting air from the internal air chamber to the tire cavity. The air compressor body further includes a deformable membrane valve member and an outlet valve member located within and at opposite respective ends of the internal air chamber, the membrane valve member deforming and the outlet valve member moving within the internal air chamber responsive

to actuation by the compression actuator between respective open and closed positions, whereby cyclically opening and closing the inlet and the outlet openings during an air compression cycle. The compression actuator includes a hollow containment body formed from a resilient deformable material composition and containing a quantity of a non-compressible medium. The containment body is affixed to a relatively high flex-deformation region of the tire carcass and reciprocally transforms between a deformed state and a non-deformed state to generate a deformation force against a membrane valve member surface and deform the membrane valve between the open and closed positions within the air chamber.

15th Patent 8,662,127 - Issued 4-Mar-2014
Abstract: A self-inflating tire system includes a compression actuator assembly mounted to a tire carcass for compressing air for delivery to a tire cavity. The compression actuator assembly includes a hollow containment body formed from a resilient deformable material composition and containing a quantity of a non-compressible medium. The containment body is affixed to a relatively high flex-deformation region of the tire carcass and reciprocally transforms between a deformed state and a non-deformed state responsive to deformation and recovery of the tire high flex-deformation region in a rolling tire. Accordingly, the containment body in the deformed state displaces a pressurized displaced quantity of the non-compressible medium which generates a compression force for application to a volume of air delivered to the tire cavity. A pump assembly affixes to the tire carcass and includes valves for reciprocally opening and closing the inlet opening and the outlet opening of a compressor body synchronously with the cyclic transformation of the containment body.

16th Patent 8,695,661 - Issued 15-Apr-2014
Abstract: A groove defined by groove sidewalls is positioned within the bending region of a tire sidewall. An elongate air tube positioned within the sidewall groove is in contacting engagement with the groove sidewalls and resiliently squeezes and collapses segment by segment as the groove constricts segment by segment within the rolling tire footprint. A longitudinally oriented projecting locking rib extends from a tube sidewall and registers within a complementary configured and located detent extending adjacent the groove to deter lateral movement of the tube within the groove after insertion. An annular projecting ridge extends from the groove for engaging the sidewalls of the air tube to deter an axial movement of the tube within the groove after insertion.

17th Patent 8,701,726 - Issued 22-Apr-2014
Abstract: A self-inflating tire assembly includes an air tube connected to a tire and defining an air passageway, the air tube being composed of a flexible material operative to allow an air tube segment opposite a tire footprint to flatten, closing the passageway, and resiliently unflatten into an original configuration. The air tube is sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air along the passageway to an inlet device for exhaust from the passageway or to an outlet device for direction into the tire cavity. The inlet device is positioned within the annular passageway 180 degrees opposite the outlet device such that sequential flattening of the air tube by the tire footprint effects pumping of air along the air passageway with the tire rotating in either

a forward or reverse direction of rotation. The invention further includes an inlet device for regulating the inlet flow of the air tube pump.

18th Patent 8,746,306 - Issued 10-Jun-2014
Abstract: A self-inflating tire assembly includes an air tube connected to a tire and defining an air passageway, the air tube being composed of a flexible material operative to allow an air tube segment opposite a tire footprint to flatten, closing the passageway, and resiliently unflatten into an original configuration. The air tube is sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air along the passageway to an inlet device for exhaust from the passageway or to an outlet device for direction into the tire cavity. The inlet device is positioned within the annular passageway 180 degrees opposite the outlet device such that sequential flattening of the air tube by the tire footprint effects pumping of air along the air passageway with the tire rotating in either a forward or reverse direction of rotation. The invention further includes an outlet device for regulating the tire cavity pressure and flow into the cavity.

19th Patent 8,820,369 - Issued 02-Sep-2014
Abstract: A self-inflating tire assembly includes an air tube connected to a tire and defining an air passageway, the air tube being composed of a flexible material operative to allow an air tube segment opposite a tire footprint to flatten, closing the passageway, and resiliently unflatten into an original configuration. The air tube is sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air along the passageway to an inlet device for exhaust from the passageway or to an outlet device for direction into the tire cavity. The inlet device is positioned within the annular passageway 180 degrees opposite the outlet device such that sequential flattening of the air tube by the tire footprint effects pumping of air along the air passageway with the tire rotating in either a forward or reverse direction of rotation. The invention further includes an outlet device for regulating the tire cavity pressure and flow into the cavity.

20th Patent 8,820,376 - Issued 02-Sep-2014
Abstract: A diaphragm pump for use in a self-inflating tire assembly is disclosed. The assembly includes a tire mounted to a rim tire mounting surface. The tire has an internal cavity. The invention further includes a pump device mounted to the rim, and the pump device has a first end and a second end, the first end being mounted within the tire cavity and the second end located outside the rim and in fluid communication with the outside air. The first end of the pump device has a flexible member having an outer rim and an inner rim, wherein the outer rim is connected to a backing plate and an inner rim is connected to a piston, wherein the piston is slidably mounted within a chamber of the backing plate. The piston has an inner passageway for fluid communication with the tire cavity and the chamber, and the second end of the pump device has an internal bore in fluid communication with the outside air and the chamber.

21st Patent 8,826,955 – Issued 09-Sep-2014
Abstract: A tire assembly includes a tire, sidewalls, and a sidewall groove. The tire has a pneumatic cavity. The sidewall has at least one bending region operatively bending when radially within a rolling tire footprint of the tire. The sidewall groove is defined by groove

sidewalls positioned within the bending region of the tire sidewall. The sidewall groove deforms segment by segment between a non-deformed state and a deformed, constricted state in response to the bending of the sidewall bending region when radially within the rolling tire footprint. An air passageway is defined by the sidewall groove and a cover strip. The air passageway resiliently deforms segment by segment between an expanded condition and an at least partially collapsed condition in response to respective segment by segment deformation of the sidewall groove when radially within the rolling tire footprint.

22nd Patent 8,851,132 - Issued 10/07/2014
Abstract: A tire has an elongate profiled sidewall groove extending into a first tire sidewall from an outward first sidewall surface. An elongate air tube is positioned within the elongate sidewall groove in contact with the groove sidewalls, the air tube having an external surface configuration corresponding with and seating within the internal sidewall configuration defining the sidewall groove. The air tube when subject to outward originating impinging force collapses from an expanded unstressed configuration into a collapsed configuration to allow the tube to insert through the groove entry opening and expand outwardly once within the sidewall groove to its unstressed configuration. The configuration of the groove sidewalls capture the air tube within the groove in its expanded unstressed configuration to prevent separation of the tube from the tire during use.

23rd Patent 8,852,371 - Issued 10/07/2014
Abstract: A method of forming an air passageway in a an air maintenance tire carcass includes: embedding an elongate strip within a pre-cured flexible tire component of a pre-cured tire carcass, the elongate strip extending in a longitudinal direction between an air inlet cavity and an air outlet cavity in the flexible tire component; curing the pre-cured tire carcass including the flexible tire component; extracting the elongate strip longitudinally end-to-end from occupancy within the flexible tire component; and defining an air passageway in the flexible component by the space previously occupied by the withdrawn elongate strip. A free end portion of the strip is accessible at either the air inlet cavity or the air outlet cavity, and the elongate strip may be extracted from either the air inlet cavity or the air outlet cavity by a tensile withdrawal force applied to the elongate strip free end

24th Patent 8,857,484 – Issued 10/14/2014
Abstract: A self-inflating tire assembly includes an air tube connected to a tire and defining an air passageway, the air tube being composed of a flexible material operative to allow an air tube segment opposite a tire footprint to flatten, closing the passageway, and resiliently unflatten into an original configuration. The air tube is sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air along the passageway to an inlet device for exhaust from the passageway or to an outlet device for direction into the tire cavity. The inlet device is positioned within the annular passageway 180 degrees opposite the outlet device such that sequential flattening of the air tube by the tire footprint effects pumping of air along the air passageway with the tire rotating in either a forward or reverse direction of rotation. The invention further includes an inlet device for regulating the inlet flow of the air tube pump.

25th Patent 8,875,762 - Issued 11/04/2014

Abstract: An air maintenance tire and connector system includes a tire carcass having an elongate integral air passageway contained within a flexible tire component of the tire carcass between an air inlet and an air outlet cavity and a connector assembly inserted within an outlet one of the cavities. The connector assembly includes a hollow right angled elbow-shaped body fitting within the outlet cavity. The elbow-shaped body's second housing segment has an axial length sufficient to project axially inward from the first housing segment through a tire wall thickness to a tire central cavity. A valve device attaches to a remote end of the second housing segment within the tire cavity, the valve device operative to regulate air flow between the elbow-shaped body central chamber and the tire cavity.

26th Patent 8,915,277 - Issued 12/23/2014
Abstract: An air maintenance tire and connector system includes a tire carcass having an elongate integral air passageway contained within a flexible tire component of the tire carcass between an air inlet and an air outlet cavity and a connector assembly inserted within one or both of the cavities. A coupling post having an axial bore extends from the hollow body through a tire wall thickness to a tire central cavity. A remote end of the coupling post is operative for sequential alternative attachment to a punch device for penetrating in a pre-cure procedure through the tire wall thickness to the tire central cavity.

27th Patent 8,944,126 - Issued 2/3/15
Abstract: A pneumatic tire assembly includes a tire, a filter element disposed between a pneumatic cavity and atmosphere. The filter element has threads for securing to the pneumatic tire. First and second sidewalls extend respectively from first and second tire bead regions to a tire tread region. The first sidewall has a bending region operatively bending when radially within a rolling tire footprint. A sidewall groove defines groove walls positioned within the bending region of the first tire sidewall. The sidewall groove deforms in response to bending of the bending region of the first sidewall while radially within the rolling tire footprint. An air passageway is defined by the sidewall groove and deforms when radially within the rolling tire footprint.

28th Patent 8,960,249 - Issued 2/24/15
Abstract: A self-inflating tire assembly includes an air tube connected to a tire and defining an air passageway, the air tube being composed of a flexible material operative to allow an air tube segment opposite a tire footprint to flatten, closing the passageway, and resiliently unflatten into an original configuration. The air tube is sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air along the passageway to an inlet device for exhaust from the passageway or to an outlet device for direction into the tire cavity.

29th Patent US 8,985,171 - Issued 3/24/2015
Abstract: A connector system and tire assembly includes an elongate integral air passageway contained within a flexible tire component of a tire carcass, the air passageway extending between an air inlet cavity and an air outlet cavity in the flexible tire component, and the air passageway extending at least a partial circumferential path around the tire carcass. A hollow dome-shaped inlet nut seats within the inlet cavity and a hollow dome-

shaped outlet nut seats within the outlet cavity. The inlet nut couples to an air inlet device for conducting air external to the tire carcass into the inlet nut central chamber; and the outlet nut outward body side couples to a valve device positioned within the tire cavity.

30th Patent 8,991,456 - Issued 3/31/2015
Abstract: An air maintenance tire and pump assembly includes an elongate annular air passageway enclosed within a bending region of a tire, the air passageway operatively closing and opening segment by segment as the bending region of the tire passes through a rolling tire footprint to pump air along the air passageway. A pair of inline valves are positioned on respective opposite sides of an inlet junction and direct a flow of inlet air in opposite directions into the air passageway; and a pair of outlet valves are positioned at a downstream side of a respective inline valve and direct a flow of the inlet air from the downstream side of a respective inline valve toward the tire cavity. The valves are selectively opened by a direction of air flow within the air passageway which, in turn, is directionally determined by the direction in which the tire rotates.

31st Patent 9,045,005 - Issued 6/02/15
Abstract: A tire assembly includes a tire having a pneumatic cavity, first and second sidewalls, a sidewall groove, an air passageway, and a pressure regulator mounted to an inner surface of the pneumatic tire cavity. The pressure regulator controls air pressure within the pneumatic tire cavity. The first and second sidewalls extend respectively from first and second tire bead regions to a tire tread region. The first sidewall has at least one bending region operatively bending when circumferentially within a rolling tire footprint. The sidewall groove defining groove sidewalls positioned within the bending region of the first tire sidewall. The groove and air passageway deform segment by segment between a non-deformed state and a deformed, constricted state in response to the bending of the first sidewall bending region circumferentially within the rolling tire footprint.

32nd Patent 9,050,858 - Issued 6/09/2015
Abstract: The invention relates generally to air maintenance tires and, more specifically, to a pump mechanism for supplying air into such tires.

33rd Patent 9,056,435 - Issued 6/16/2015
Abstract: A pneumatic tire assembly includes a pneumatic tire having an inner cavity and an inner surface at least partially defining the inner cavity, a rigid structure for facilitating operation of the tire assembly, and a docking base for securing the rigid structure to the inner surface of the inner cavity. The docking base has been integrally bonded to the inner surface during curing of the pneumatic tire. The docking base has a shape formed by a mold attached to the inner surface of the inner cavity during curing of the pneumatic tire. The mold subsequently is removed thereby resulting in the docking base integrally secured to the inner surface.

34th Patent 9,056,533 - Issued 6/16/2015
Abstract: An elongate air tube is positioned within a tire sidewall cavity in contacting internal engagement with the tire sidewall to form an assembly. The air tube includes an internal elongate air passageway and wing projections projecting in opposite directions at an

axially inward body portion. The wing projections seat within cavity pockets to retain the air tube within the cavity. The air tube body operatively compresses responsive to impinging stress forces from the tire sidewall against the air tube body, whereby the air tube body reconfiguring from an expanded unstressed configuration into a compressed configuration to constrict the air passageway. The air tube body decompresses into the expanded configuration upon reduction of the impinging stress forces against the air tube body.

35th Patent 9,061,556 - Issued 6/23/2015
Abstract: The present invention is directed to a pneumatic tire with an elongate substantially annular air passageway enclosed within a bending region of the tire and extending substantially in a circumferential direction, wherein upon rolling of the tire air is pressed through the air passageway and a valve assembly in air flow communication with the tire cavity, the annular air passageway and the exterior of the tire and having an air inlet for allowing air to enter the valve assembly from the exterior of the tire as well as an air outlet for allowing air to enter the tire cavity.

36th Patent 9,073,395 - Issued 7/22/15
Abstract: A tire has an elongate profiled sidewall groove extending into a first tire sidewall from an outward first sidewall surface. An elongate air tube is positioned within the elongate sidewall groove in contact with the groove sidewalls, the air tube having an external surface configuration corresponding with and seating within the internal sidewall configuration defining the sidewall groove. The air tube when subject to outward originating impinging force collapses from an expanded unstressed configuration into a collapsed configuration to allow the tube to insert through the groove entry opening and expand outwardly once within the sidewall groove to its unstressed configuration. The configuration of the groove sidewalls capture the air tube within the groove in its expanded unstressed configuration to prevent separation of the tube from the tire during use.

37th Patent 9,108,476 - Issued 8/18/15
Abstract: An air maintenance tire and pump assembly includes a pair of inline valves are positioned on respective opposite sides of an in-tire air passageway inlet junction and a pair of outlet valves positioned at a downstream side of a respective inline valve. A bypass valve is further provided extending between the downstream valve sides of the inline valves, the bypass valve operative to open and bypass the flow of inlet air through the outlet valves to the tire cavity in the event that a tire cavity pressure is greater than a preset pressure level and close when a tire cavity pressure is less than the preset pressure level.

38th Patent 9,114,673 - Issued 8/25/15
Abstract: An air maintenance tire and pump assembly includes a tire having a tire cavity, first and second sidewalls extending from first and second tire bead regions, respectively, to a tire tread region, an elongate substantially annular air passageway enclosed within a bending region of the sidewalls, the air passageway operatively closing and opening, segment by segment, as the bending region of the sidewalls passes adjacent a rolling tire footprint to pump air along the air passageway, an air inlet port assembly coupled to, and in air flow communication with, the air passageway, the air inlet port assembly being operable

to channel inlet air from outside of the tire into the air passageway, the air inlet port assembly including an inlet control valve and an outlet tee structure positioned 180° opposite the inlet control valve in the air passageway for moving air into the tire cavity, the inlet control valve including two inlet check valves for ensuring air flow only into, and not out of, the inlet control valve, the air passageway, a corresponding plain tee inlet structure, and the tire cavity, and a pressure relief valve for relieving a volume equal to a last segment volume of the air passageway plus a volume of the outlet tee structure.

39th Patent 9,126,462 - Issued 9/8/15
Abstract: A self-inflating tire assembly includes an air passageway in the tire that is operable to be sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air from an inlet device through the passageway to an outlet device for direction into the tire cavity. A valve device for a tire is also disclosed. The valve device includes an insert mounted in the tire, a valve body mounted within the valve insert; wherein the valve body has a first, second and third chamber, wherein a first and second check valve is positioned in the first and second chamber. A pressure membrane is received within the valve body, and positioned to open and close the third chamber. The pressure membrane is in fluid communication with the tire cavity and the third chamber of the valve body. A spring is received within the third chamber and is positioned to exert force upon the pressure membrane to bias the pressure membrane position relative to the channel in the open position.

40th Patent 9,193,226- Issued 11/24/15
Abstract: The invention relates to an air compressor mountable in an annular tire cavity of a pneumatic tire. The compressor comprises an air inlet, an air outlet, and a body in which are formed a blind hole having a sidewall and a compression chamber in fluid communication with the air inlet and the air outlet. Further, the tire comprises a compression piston configured for reciprocating in the compression chamber for providing compressed air to the tire cavity through the air outlet, and a hydraulic fluid passage for providing hydraulic fluid into the blind hole, as well as a guiding piston configured for reciprocating in the blind hole in sealed contact with the sidewall and for guiding a reciprocating movement of the body relative to the compression piston. The invention further relates to a tire assembly comprising a tire and the compressor.

41st Patent 9,199,518 - Issued 12/1/15
Abstract: A method of assembling an air pump in a tire is provided including: opening an axial air passageway of an elongate flexible air tube at one end; inserting one by one a plurality of one-way check valves into the air passageway from the one end to form an axial array of spaced apart check valves along the air passageway, each check valve having an external nominal width greater than a nominal width of the air tube passageway; establishing a press fit engagement between each check valve and air tube internal sidewalls defining the air passageway to place each check valve at a respective preferred position within the air passageway; retaining the check valves in the respective preferred positions within the air passageway by radial pressure from the air tube internal sidewalls and closing the one end of the flexible air tube.

42nd Patent 9,205,712 - Issued 12/8/15
Abstract: An air maintenance tire includes an air inlet housing affixed to the inner liner of a tire. An elongate sidewall air pumping passageway is incorporated within a first tire sidewall. An intake conduit and an elongate tubular inlet conduit are provided having a quick connect/disconnect latching attachment to sockets formed by the air inlet housing.

43rd Patent 9,205,714 - Issued 12/8/15
Abstract: A self-inflating tire assembly includes an air passageway in the tire that is operable to be sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air from an inlet device through the passageway to an outlet device for direction into the tire cavity. A valve device for a tire is also disclosed. The valve device includes an insert mounted in the tire, a valve body mounted within the valve insert; wherein the valve body has a first, second and third chamber, wherein a first and second check valve is positioned in the first and second chamber. A pressure membrane is received within the valve body, and positioned to open and close the third chamber. The pressure membrane is in fluid communication with the tire cavity and the third chamber of the valve body. A spring is received within the third chamber and is positioned to exert force upon the pressure membrane to bias the pressure membrane position relative to the channel in the open position.

44nd Patent 9,216,619 - Issued 12/22/15
Abstract: An air maintenance tire and pump assembly includes a tire having a tire cavity, first and second sidewalls extending from first and second tire bead regions, respectively, to a tire tread region, an elongate substantially annular air passageway enclosed within a bending region of the sidewalls, the air passageway operatively closing and opening, segment by segment, as the bending region of the sidewalls passes adjacent a rolling tire footprint to pump air along the air passageway, an air inlet port assembly coupled to, and in air flow communication with, the air passageway at an inlet air passageway junction, the air inlet port assembly being operable to channel inlet air from outside of the tire into the air passageway, the air inlet port assembly including an inlet control valve and an outlet tee structure positioned 180° opposite the inlet control valve in the air passageway for moving air into the tire cavity, the inlet control valve including two inlet check valves for ensuring air flow only into, and not out of, the inlet control valve, the air passageway, a corresponding plain tee inlet structure, and the tire cavity.

45th Patent 9,216,620 - Issued 12/22/15
Abstract: An air maintenance tire includes an air inlet housing affixed to the inner liner of a tire. An elongate sidewall air pumping passageway is incorporated within a first tire sidewall. An elongate air tube is contained within the first sidewall and has an elongate elliptical internal air passageway. The air tube is configured having a substantially on-side mushroom-shaped sectional shape extending radially into the first tire sidewall formed by a radially inward tube cap and a radially outward tube stem. Inlet and intake conduits connect into sockets of the inlet housing and a pressure regulating valve system within the inlet housing controls pressurized air flow from the tube internal air passageway into the tire cavity.

46th Patent 9,259,975 - Issued 2/16/16
Abstract: The invention relates generally to a pneumatic rubber tire which contains an outer, annular, circular groove which contains a flexible tube bonded to the walls of the groove.

47th Patent 9,259,981 – Issued 2/16/16
Abstract: An air maintenance tire assembly and method of operation includes a pressurized air supply assembly for supplying pressurized air to a tire cavity through an elongate outward projecting, valve stem passageway. An elongate centrally disposed shaft within the valve stem reciprocally moves axially in the valve stem internal air passageway between a passageway-opening axial position and a passageway-closing axial position. A pressure regulator is provided to move the elongate shaft axially between the passageway-opening and passageway-closing positions responsive to a detected air pressure level within the tire cavity.

48th Patent 9,272,586 – Issued 3/1/16
Abstract: A valve stem-based air maintenance tire assembly and method of operation is provided employing a tire mounted air pumping system, The assembly includes a rim-mounted pressure regulator positioned within a tire cavity opposite an inward end of a tire valve stem to selectively open and close pressurized air flow from a valve stem internal passageway into the tire cavity. An elongate valve stem shaft is mounted within the valve stem air passageway and reciprocally moves axially to close off and open the valve stem air passageway to create or close a pressurized air path into the tire cavity as needed.

49th Patent 9,302,556 - Issued 4/5/16
Abstract: An air maintenance tire and air pump assembly includes a sidewall and a tire cavity for maintaining pressure; an elongate tubular air passageway enclosed within a flexing region of the sidewall, air passageway, the air passageway operably closing segment by segment in reaction to induced forces from the tire flexing region as the flexing region of the tire wall rotates adjacent a rolling tire footprint, the elongate air passageway having at least one check valve device seated within the axial air passageway; and a relief valve assembly comprising a chamber body, a valve, a piston, and a silicone ring, the valve having a valve body and a valve head, the valve head, deforming to release over-pressurized air from the tire cavity to atmosphere.

50th Patent 9,308,784 - Issued 4/12/16
Abstract: A self-inflating tire assembly comprises a tire having a tread region, first and second sidewalls, and first and second bead regions, wherein the first and second sidewalls extend respectively from the first and second bead regions to the tread region, wherein the tread region and the first and second sidewalls enclose an annular tire cavity. Further, the assembly comprises an air passageway connected to one of the sidewalls and extending essentially in a circumferential direction of the tire for pumping air from outside of the tire into the tire cavity, wherein the air passageway has an air passageway inlet for receiving air from outside of the tire and an air passageway outlet for releasing air into the tire cavity. Moreover, the assembly comprises an air pressure regulator having an air pressure regulation chamber, a connector end, and a channel fluidly connecting the pressure

regulation chamber with the connector end, wherein the air pressure regulator is detachably connected to one of the air passageway inlet and the air passageway outlet via the connector end for allowing fluid communication between channel and the air passageway via the connector end. In addition, the invention relates to a pressure regulator kit for regulating the pressure of a tire, the kit comprising a plurality of air pressure regulators.

51st Patent 9,308,787 - Issued 4/12/16
Abstract: An air compressor mountable within an annular cavity of a pneumatic tire comprises an air inlet for receiving air to be pumped into the tire cavity, an air compression chamber in fluid communication with the air inlet, and an air outlet in fluid communication with the air compression chamber. Further, the compressor comprises a pressure compensation chamber in fluid communication with the tire cavity when the air compressor is mounted within the tire cavity, and a double piston having a shaft and two opposing piston ends, the shaft rigidly connecting both piston ends with each other, wherein the first piston end is arranged and movable in the compression chamber and is actuatable by hydraulic pressure between a compression state and an intake state, and wherein the second piston end is arranged and movable in the pressure compensation chamber and subject to the pressure of the tire cavity when the compressor is mounted within the tire cavity. Moreover, the present application is directed to a tire comprising the aforementioned air compressor.

52nd Patent 9,327,560 – Issued 5/3/16
Abstract: A tire having a tire cavity is disclosed, wherein the tire has a bi-directional pump assembly including a pump passageway having an inlet end and an outlet end, and being operative to allow a portion of the pump passageway near a tire footprint to substantially close and open the pump passageway. The tire includes a valve assembly having a valve housing, wherein a diaphragm is mounted in the valve housing forming an interior chamber, and wherein the diaphragm is responsive to the pressure of the tire cavity. The interior chamber has a first hole in fluid communication with the inlet end of the pump passageway, a second hole in fluid communication with the outlet end of the pump passageway, and a third hole in fluid communication with the outside air. The valve housing has a passageway in fluid communication with the tire cavity and the outlet end of the pump. The valve assembly further includes an inlet control valve having a valve bottom positioned over the third hole and operative to open and close the third hole to allow air to enter the system. The inlet control valve has a first end connected to the diaphragm, and a resilient member biases the inlet control valve into the open position.

53rd Patent 9,327,561 – Issued 5/3/16
Abstract: A tire having a tire cavity is disclosed, wherein the tire has a bi-directional pump assembly including a pump passageway having an inlet end and an outlet end, and being operative to allow a portion of the pump passageway near a tire footprint to substantially close and open the pump passageway. The tire includes a valve assembly having a valve housing, wherein a diaphragm is mounted in the valve housing forming an interior chamber, and wherein the diaphragm is responsive to the pressure of the tire cavity. The interior chamber has an inlet in fluid communication with outside air, and an outlet in fluid communication with inlet and outlet of the pump passageway. The diaphragm is positioned

over the outlet and operative to open and close the outlet. A resilient member biases the diaphragm into the open position.

54th Patent 9,327,562 – Issued 5/3/16
Abstract: A pumping mechanism is used with a pneumatic tire mounted on a wheel rim to keep the pneumatic tire from becoming underinflated. The pumping mechanism includes a plurality of pumps forming a linear belt and subsequently being attached circumferentially to the wheel rim, a plurality of pump holders interconnecting the plurality of pumps in a linear configuration, and a control valve for controlling inlet air into a tire cavity of the pneumatic tire.

55th Patent 9,333,816 – Issued 5/10/16
Abstract: An air maintenance tire assembly includes a tire having an elongate valve stem projecting outward from the tire cavity and a tire sidewall having an elongate sidewall groove formed therein and housing an elongate air tube. A connecting tube extends between the air tube and the valve stem, the connecting tube having an internal connecting air passageway for directing air forced along the air tube air passageway into the internal valve stem passageway as the tire rolls over a ground surface.

56th Patent 9,333,817 – Issued 5/10/16
Abstract: A pneumatic tire comprises a sidewall, an annular tire cavity, and a hydraulic actuator connected to the sidewall inside the annular tire cavity, wherein the hydraulic actuator has a flexible reservoir for containing a hydraulic fluid, and an opening allowing hydraulic fluid to enter the reservoir and to exit the reservoir. Further, the hydraulic actuator comprises a lever arm connected to the sidewall and holding the flexible reservoir between the lever arm and the sidewall, wherein the lever arm comprises a fluid channel allowing hydraulic fluid to flow from the reservoir through the opening out of the lever arm.

57th Patent 9,340,076 – Issued 5/17/16
Abstract: A tire assembly and method includes one or more elongate air passageway formed within a tire component, such as a tire sidewall. The air passageway is configured as a series or string of elongate cavities, adjacent cavities connected end to end by an elongate connecting channel. The connecting channel is dimensioned having a channel diametric size smaller than a cavity diametric size. Positioned within the tire component, the air passageway sequentially collapses segment by segment as each of the cavities pass sequentially over a rolling tire footprint. Air is pumped by the sequential air passageway collapse with the smaller dimensioned connecting channel(s) acting as valve components to directionally keep the pumped air moving between an air passageway air inlet and an air passageway air outlet and from there into the tire cavity

58th Patent 9,340,077 – Issued 5/17/16
Abstract: An air compressor mountable to a sidewall of an annular tire cavity, wherein the compressor comprises an air inlet for receiving air to be pumped into the tire cavity and an air outlet for releasing air into the tire cavity. Further, the compressor comprises a double membrane assembly having a first membrane and a second membrane arranged in parallel to the first membrane. A pressure compensation chamber is provided between the first

membrane and the second membrane, the pressure compensation chamber being in fluid communication with the tire cavity. Further, an air compression chamber is arranged on a side of the second membrane opposite to the pressure compensation chamber, wherein the compression chamber is in fluid communication with the air inlet and the air outlet. Moreover, a tire comprises the aforementioned compressor.

59th Patent 9,365,084 – Issued 6/14/16
Abstract: A self-inflating tire assembly includes an air tube connected to a tire and defining an air passageway, the air tube being composed of a flexible material operative to allow an air tube segment opposite a tire footprint to flatten, closing the passageway, and resiliently unflatten into an original configuration. The air tube is sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air along the passageway to a regulator device. The regulator device regulates the inlet air flow to the air tube and the outlet air flow to the tire cavity.

60th Patent 9,381,780 – Issued 7/5/16
Abstract: A tire having a tire cavity is disclosed, wherein the tire has a bi-directional pump assembly including a pump passageway having an inlet end and an outlet end, and being operative to allow a portion of the pump passageway near a tire footprint to substantially close and open the pump passageway. The tire includes a valve assembly having a valve housing, wherein a diaphragm is mounted in the valve housing forming an interior chamber, and wherein the diaphragm is responsive to the pressure of the tire cavity. The interior chamber has an inlet in fluid communication with outside air, and an outlet in fluid communication with inlet and outlet of the pump passageway. The valve assembly further includes an inlet control valve having a valve bottom positioned over the outlet and operative to open and close the outlet. The inlet control valve has a first end connected to the diaphragm, and a resilient member biases the inlet control valve into the open position.

61st Patent US 9,381,781 - Issued 7/5/16
Abstract: A pneumatic tire assembly includes: a tire having a pneumatic cavity; a rigid structure for facilitating operation of the tire assembly, the rigid structure being bonded to the tire by a layered thermoplastic material such that a stiffness gradient is created between the structure and the tire; first and second sidewalls extending respectively from first and second tire bead regions to a tire tread region, the first sidewall having at least one bending region operatively bending when radially within a rolling tire footprint; and a sidewall groove defined by groove walls positioned within the bending region of the first tire sidewall, the sidewall groove deforming segment by segment between a non-deformed state and a deformed, constricted state in response to bending of the bending region of the first sidewall while radially within the rolling tire footprint.

62nd Patent 9,387,737 – Issued 7/12/16
Abstract: A tire assembly having: a tire having a tread portion and a pair of sidewalls extending radially inward from the tread portion to join with a respective bead; a supporting carcass for the tread portion and sidewalls; a pump passageway positioned within a bending region of the tire, the pump passageway being operative to open and close as the tire rotates; a valve assembly in fluid communication with the pump passageway; a pocket formed in the

tire; a filter assembly mounted in the pocket, said filter assembly being in air flow communication with the valve assembly, wherein the pocket has an area larger than the area of the filter housing wherein the valve assembly has an inlet, wherein the filter assembly has an outlet, wherein a tube connects the filter outlet assembly to the inlet of the valve assembly; wherein the tube is made of a rubber composition having a shore D hardness greater than 40 as measured by ASTM-D2240.

63rd Patent 9,409,454 – Issued 8/9/16
Abstract: A self-inflating tire assembly includes a first and second air tube mounted within a tire wherein each air tube defines an air passageway. Each air tube is composed of a flexible material operative to allow an air tube segment opposite a tire footprint to flatten, closing the passageway, and resiliently unflatten into an original configuration. Each air tube is sequentially flattened by the tire footprint in a direction opposite to a tire direction of rotation to pump air along the passageway to an outlet device for direction into the tire cavity. Each air tube has an inlet end that are joined together by an inlet device. Each air tube has an outlet end that are joined together by an outlet device The inlet device is preferably positioned 180 degrees opposite the outlet device. The inlet device allows air to transfer from one air tube to the other air tube. The outlet device allows air to transfer from one air tube to the tire cavity.

64th Patent 9,415,640 – Issued 8/16/16
Abstract: A rim mounted control assembly receives air through the tire valve stem from an air maintenance tire. A control assembly regulator controls a flow of air to and from a tire-mounted air pumping tube. The control assembly includes a bi-directional air distribution block having multiple parallel air pathways, each air pathway coupled to a respective conduit connected to an air pumping tube mounted within a tire sidewall. The pathways alternatively operate to deliver ambient non-pressurized air to the air pumping tube in response to directional tire rotation against a ground surface.

65th Patent 9,421,832 – Issued 8/23/16
Abstract: An air maintenance tire and pump assembly comprising: a tire having two spaced inextensible beads; a ground contacting tread portion; a pair of individual sidewalls extending radially inward from the axial outer edges of said tread portion to join the respective beads; a supporting carcass for the tread portion and sidewalls; an innerliner disposed radially inward of the carcass, the innerliner having a innerliner surface facing an interior cavity of the tire; an elongate substantially annular air passageway enclosed within a bending region of the tire, the air passageway operatively closing and opening segment by segment as the bending region of the tire passes through a rolling tire footprint to pump air along the air passageway; an air inlet port assembly coupled to and in air flow communication with the air passageway at an inlet air passageway junction, the air inlet port assembly operable to channel inlet air from outside of the tire into the air passageway, the air inlet port assembly comprising a regulator assembly, the regulator assembly having a mounting surface; the mounting surface adhered to the innerliner surface with a silicone adhesive.