Report and Design Presentation
Chainless Challenge 2015/2016 - WMU

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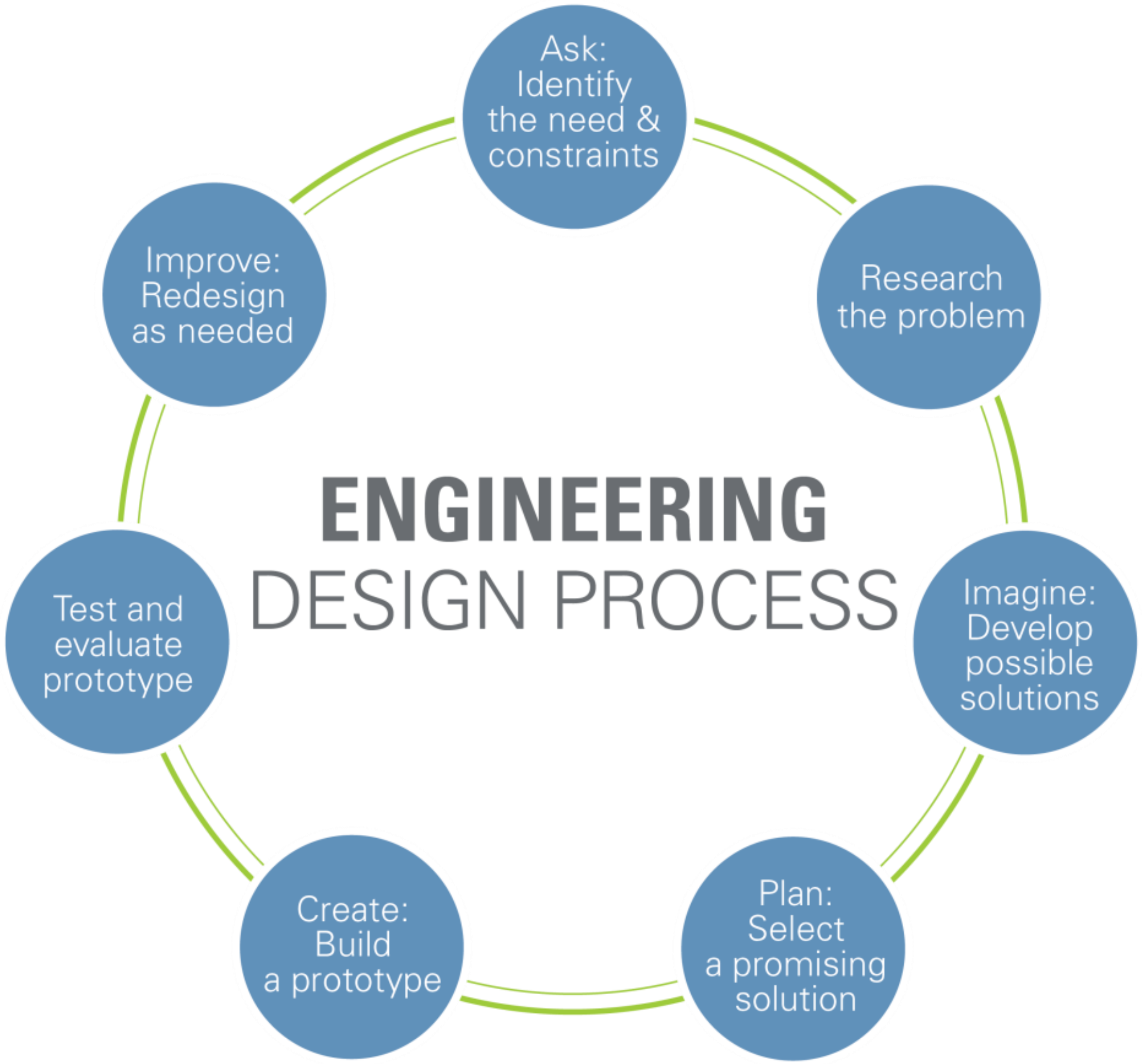
Overview

- Project Plan/Objectives
- Design Analysis and Drawings
  - Mechanical
  - Electrical
- Actual Test Data
- Cost Analysis
- Lessons Learned and Conclusions

Project Planning



Objectives - Mechanical

Design, fabricate, and test a unique human-assisted hydraulic system

- Create a system to meet regulations/objectives
- Include green engineering and sustainable process
- Minimize cost of competition vehicle
- Innovate from previous years' designs

Evaluation Criteria

Safety/Reliability

- Maintain safe operating pressure
- All components safely mounted

Innovation

- Utilize different hydraulic components

Manufacturability

- Ease of assembly and fabrication

Cost

- Lowest cost that satisfies objectives

Marketability

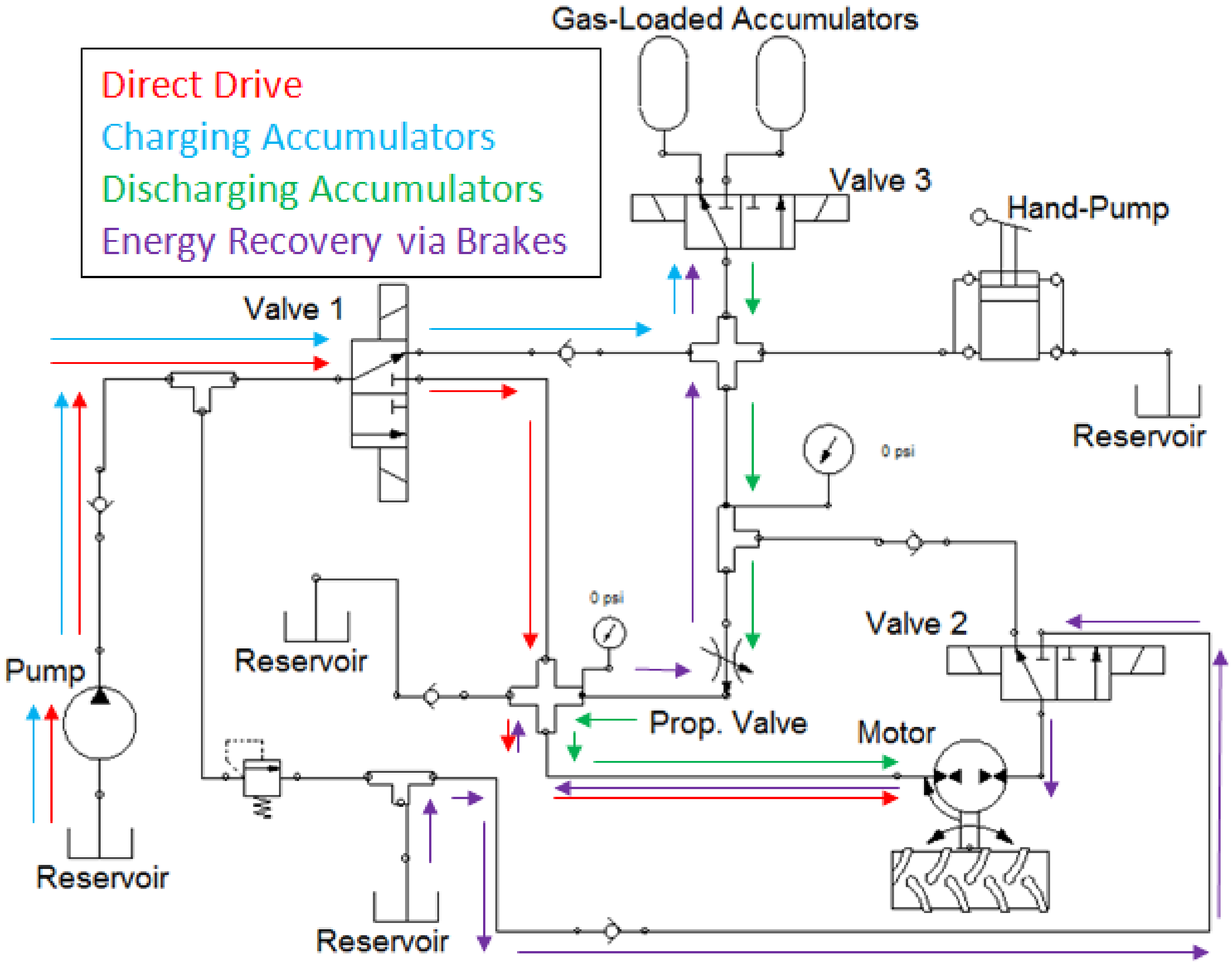
- Customer-focus on unique design

Design Analysis

Design Concepts

- Power Transmission System
  - Hydraulic fluid was the selected medium
- Vehicle Type
  - Research conducted on multiple frame types
- Brainstorming Ideas
  - Reservoir placement optimization
  - Frame extension
  - Aerodynamic shell
  - Electrical control system
  - Hub utilization

Hydraulic System



Frame Design

- Factors weighted on importance – scores averaged
- Frame extension
- Criteria:
  - Weight
  - Aerodynamics
  - Mounting Area
  - Adaptability
  - Etc. (see matrix)

Frame Decision (Upright Bicycle)

		Upright	Tricycle	Recumbent
Factors	**Weight Factor**	**Average**	**Average**	**Average**
Safety	14	6	7	7
Weight	13	9	3	5
Adaptability	12	5	8	5
Mounting Area	11	5	8	5
Maintenance	10	8	6	5
Operability	9	7	7	3
Cost	8	8	5	3
Stability	7	6	8	9
Load Limit	6	5	8	7
Drag	5	7	3	7
Maneuverability	4	8	5	5
Climbing	3	4	7	6
Rider Comfort	2	7	6	9
Aesthetics	1	9	3	6
	Total Score:	668	630	577

Pumps and Motors

Criteria:

- Safe for Mounting
- Weight
- Efficiency
- Displacement & Flow Rate
- Dimensions
- Cost

Pump/Motor Analysis

Pumps	Flow Rate out	Hydraulic HP	Volume Occupied	Total Efficiency @ 500 RPM	Weight	Displacement volume	Cost
F 11-5 P@800	2206.9 CC/m	0.271	83.66 in^3	90.4%	11 lbs	4.9CC/rev	$600
F 11-10 P@400	4315.3 CC/m	0.265	118.13 in^3	88.4%	16.5 lbs	9.8CC/rev	$715
AM1C-31	2558.9 CC/m	0.252	38.25 in^3	84% @ 600 RPM	4 lbs	5.1 CC/rev	$800
PGP505 P@800	2270.58 CC/m	0.234	34 in^3	78%	5.26 lbs	6CC/rev	$250

* H3 Eliminated due to space occupied by the pump

Accumulators

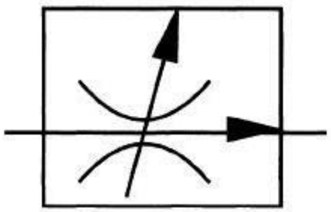
Criteria

- Capacity
- Energy Density
- Dimensions
- Weight
- Cost

Accumulator Analysis & Data

Parker Accumulators	Price ($)	Gal	Weight (lb)	Weight (w/ oil) lbs	PSI	Dims.	**Energy Density (ft-lb)/lb**
BA005B3T01A1	$704.00	0.65	16	20.98	3000	ø4” x 15”	1786.45
AD280B25T9A1	$672.00	0.74	21	26.68	3600	Ø6.75” x 9.5”	1922.11
BA01B3T01A1	$374.57	1	34	41.68	3000	ø6.75“ x 17"	1385.56
T0BUL4.5AL-20	$850	1.08	20	28.29	3000	ø4“ x 24"	2204.67

Valves, Ports and Connections



- 3-way flow control valves (4)
- Variable flow control valve (controlling accumulator pressure release) (1)
- Braided Stainless Steel lines (18ft)
- 2.5 Gallon Rigid Reservoir (1)

Gearing and Hubs

Gearing to Pump

- Highest input ratio: 1 to 11.62
- Lowest input ratio: 1 to 3.791

Motor to Wheel

- Highest output ratio: 1 to 1
- Lowest output ratio: 1 to .625

Hubs

- Front Hub: Shimano Alfine SG-S501
- Rear hub: Strumey Archer S3X

Objectives - Control System

Design and build an electronic control system to reconfigure the hydraulic circuit for all modes of operation through a simple user interface.

The system also should:

- Provide visual feedback on the status of the hydraulic circuit.
- Set efficient flow parameters for flow release from accumulators.
- Contribute to enforcing safety.

Design Criteria

Intuitive and Simple User Interface

- User commands issued by pressing on pushbuttons.
- Use as few pushbuttons as possible to cover all the control functions.
- Choose appropriate placement to support functionality.

Real-Time System Feedback

- Include graphical display to show vehicle speed, hydraulic pressures, current operation mode, and alarms in real time.

Design Criteria

Modular Design

- Control system to be developed in separate modules with specific functions to streamline prototyping, testing, and final assembly.
- Add flexibility for spatial distribution relative to other system components.

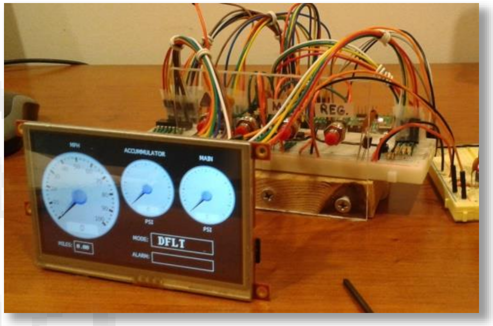
Low Cost

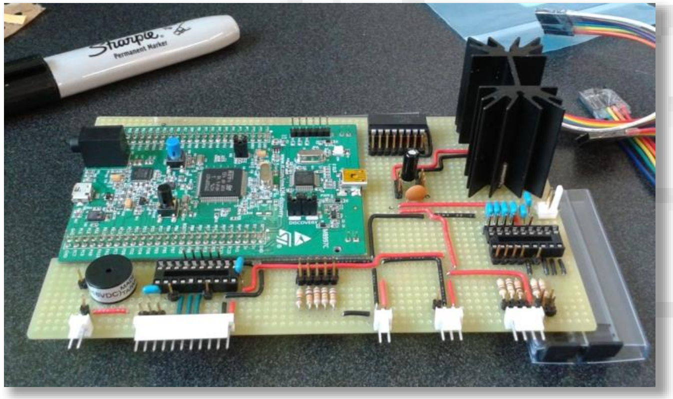
- Achieve lowest cost that satisfies the objectives.

System Components

Control Panel:

- STM32F4 Discovery microcontroller board
- LCD graphic display μLCD-43PT
- Custom-made interface board
- Connector headers for peripherals
- Push and toggle buttons
- Rigid enclosure

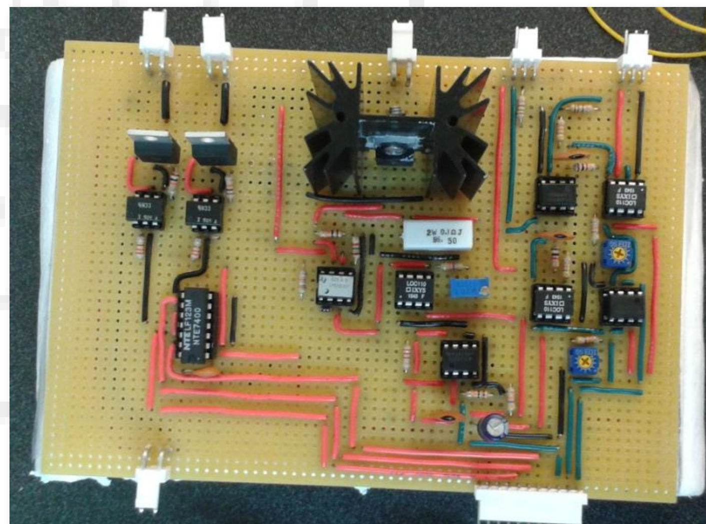




System Components

Power Control Box:

- PWM solenoid-driver circuits
- Linear voltage-controlled current source circuit
- Linear voltage isolator circuits
- Rigid enclosure



System Components

μLCD-43PT Display Code:

- 4D Graphics Language – Developed with 4D Workshop 4
- Generates, displays, and animates graphic elements

STM32F4 Discovery Microcontroller Code:

- C Language – Developed with IAR Embedded Workbench
- Processes user input to implement logic for hydraulic operation modes
- Calculates and displays sensor data
- Controls all other components in the system

Final Product and Testing

- Upon completion the final bike weight was about 168 pounds, including hydraulic fluid
- Functional testing was done on campus

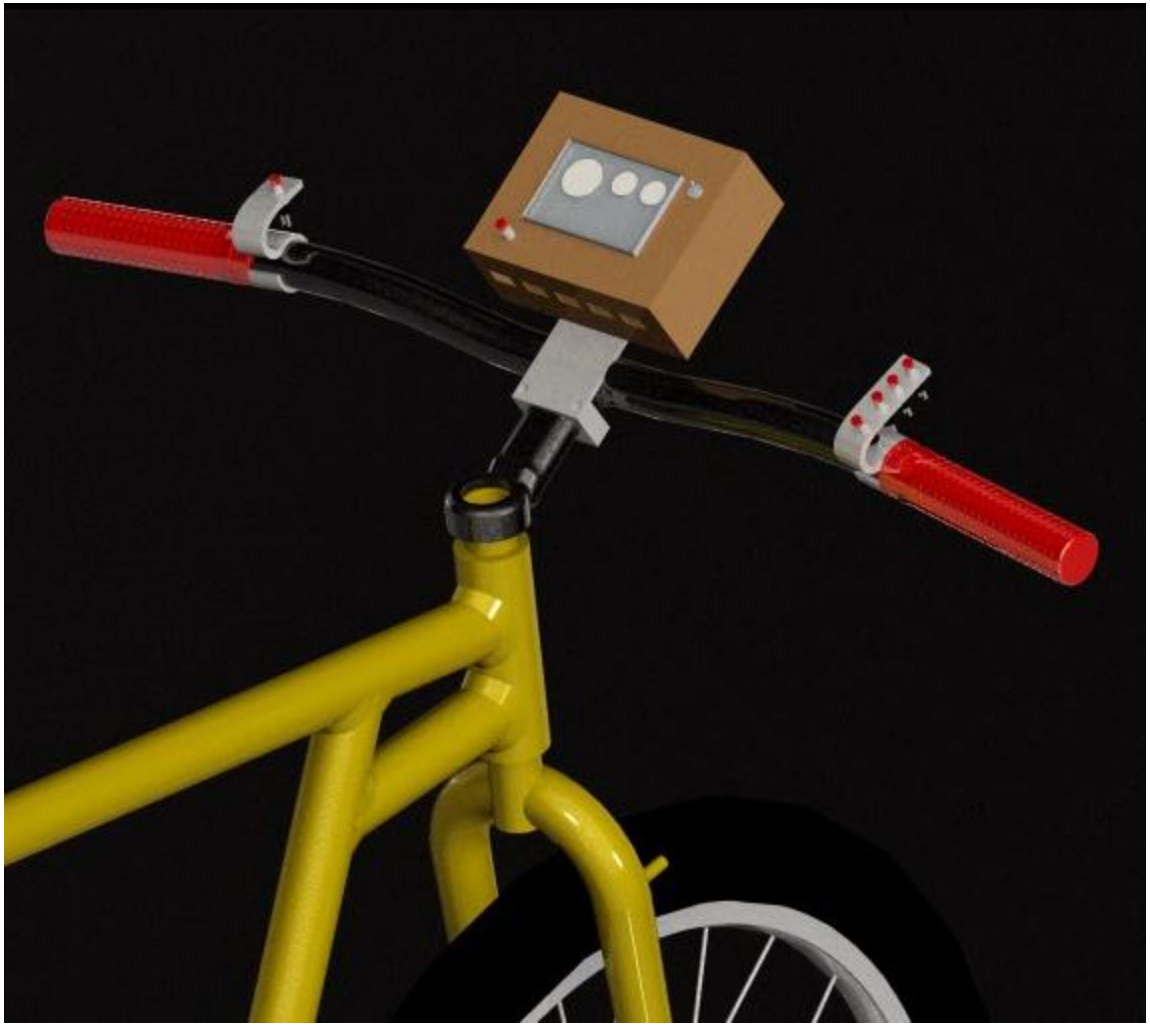
Testing included:

- Direct Drive
- Accumulator charging time
- Efficiency testing
- Electrical control testing
- Sprint testing
- Endurance testing

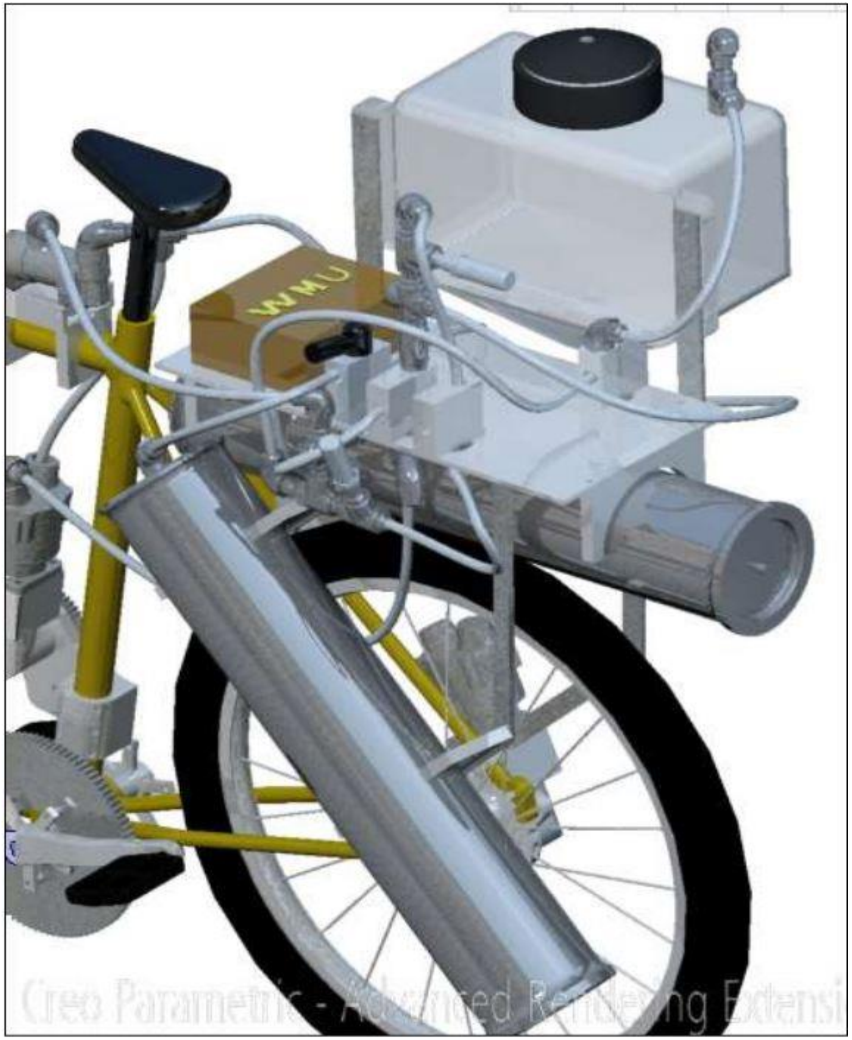
Design Drawings

- CAD and Bracket Analysis
- CAD Models
  - Handlebars, pushbuttons, and display screen
  - Rear mounting plate and components
  - Front hub, pump mount, and gear train
  - Completed bike (including manikin)

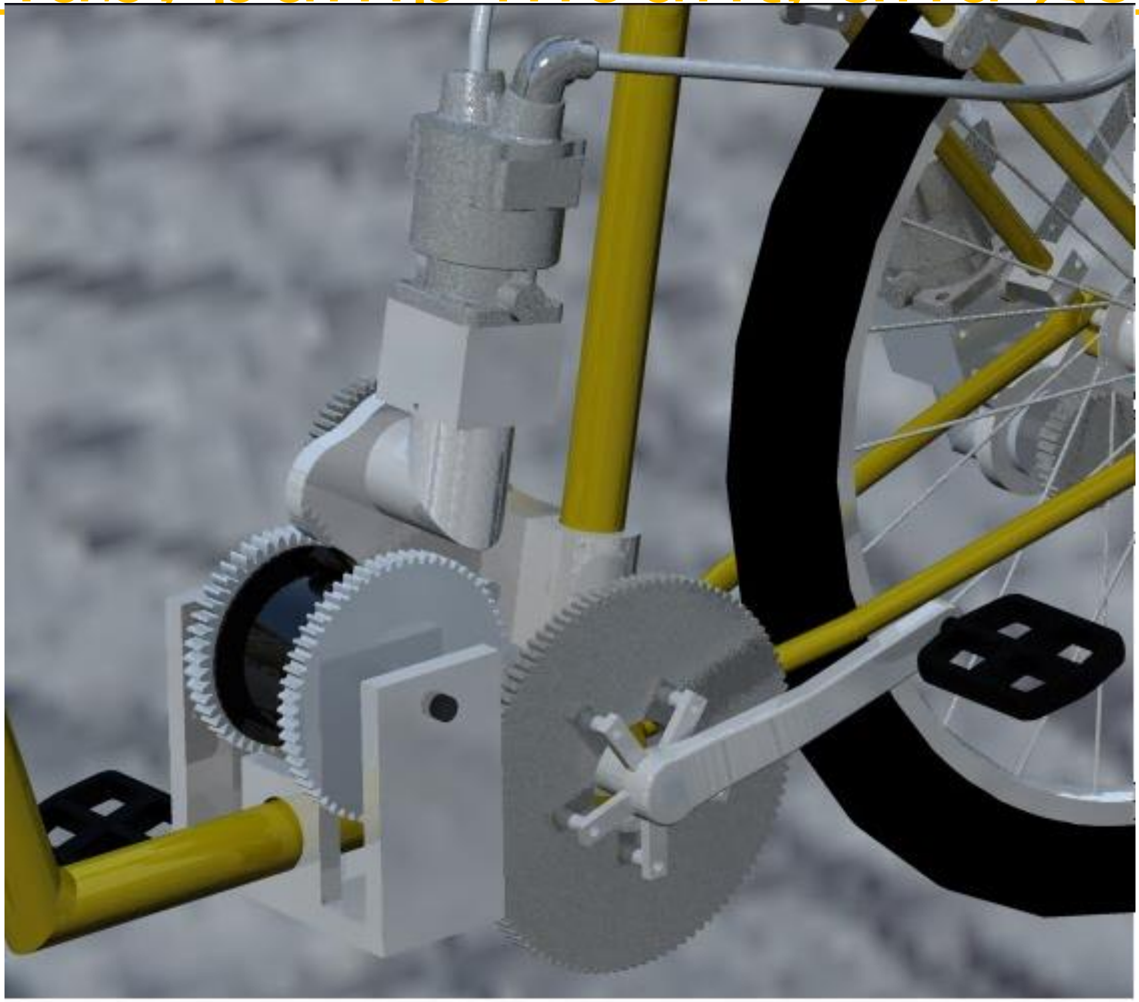
Handlebars, pushbuttons, display



Rear mounting plate and components

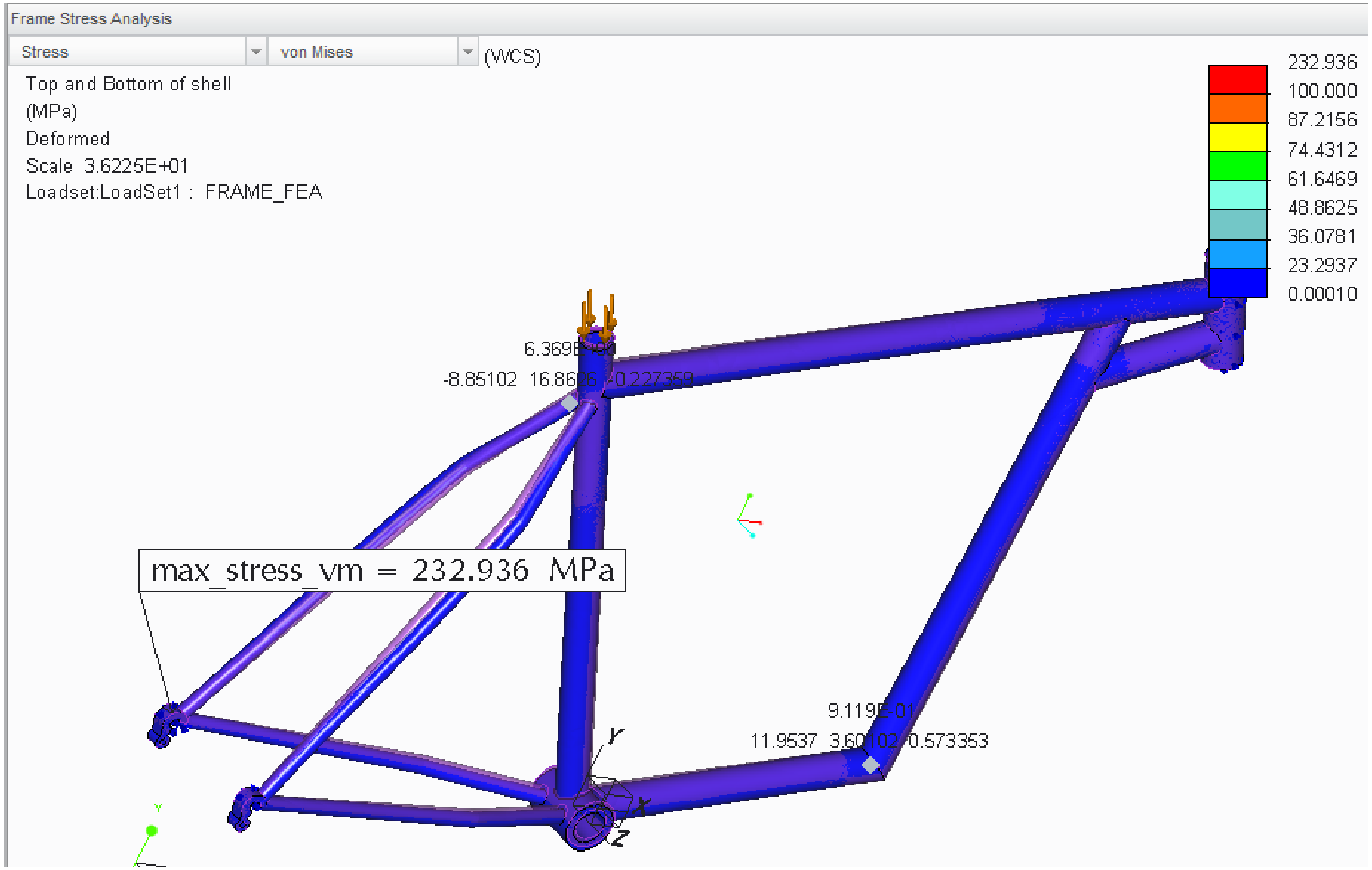


Front hub, pump mount, and gear train



Completed Bike

Finite Element Analysis



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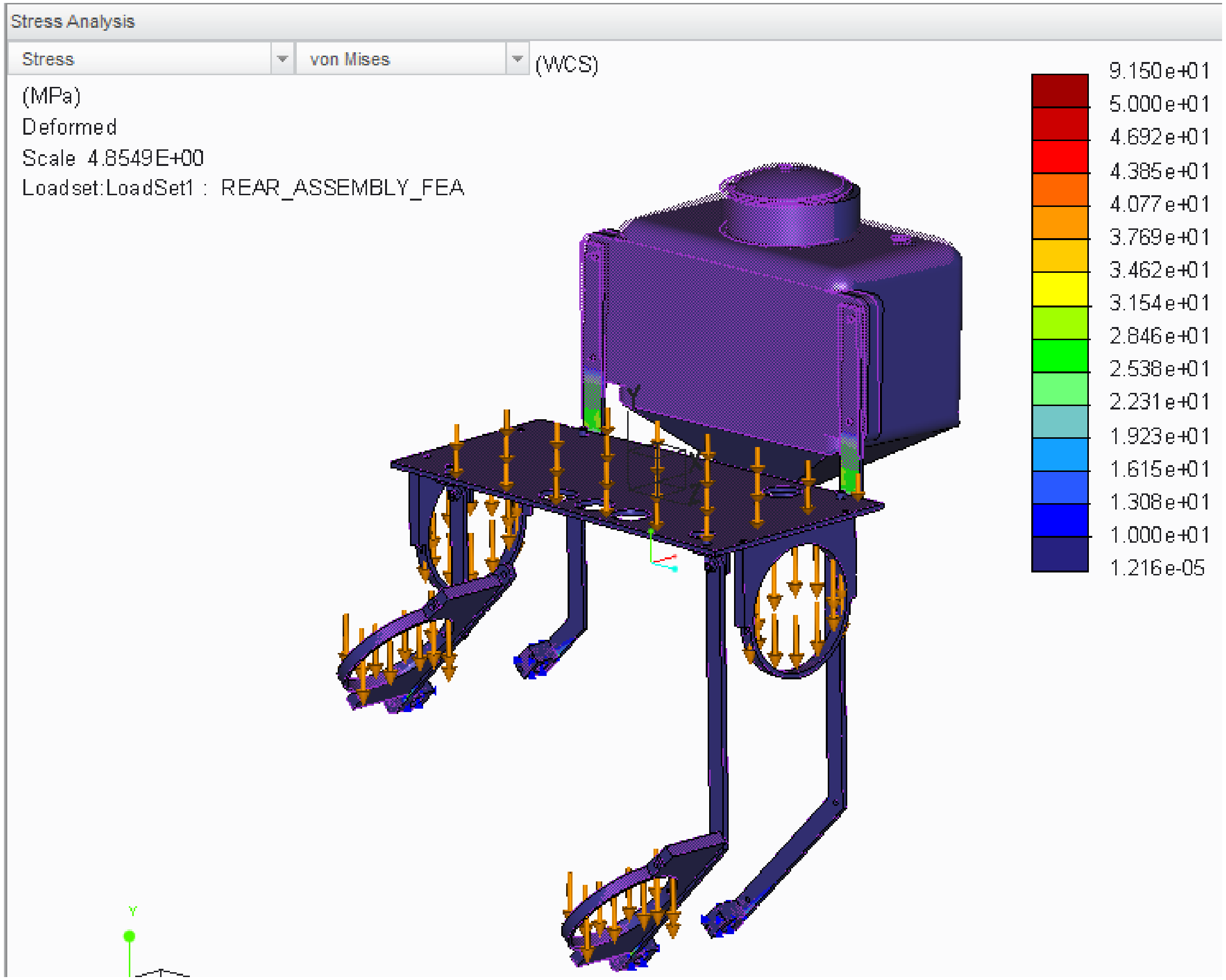

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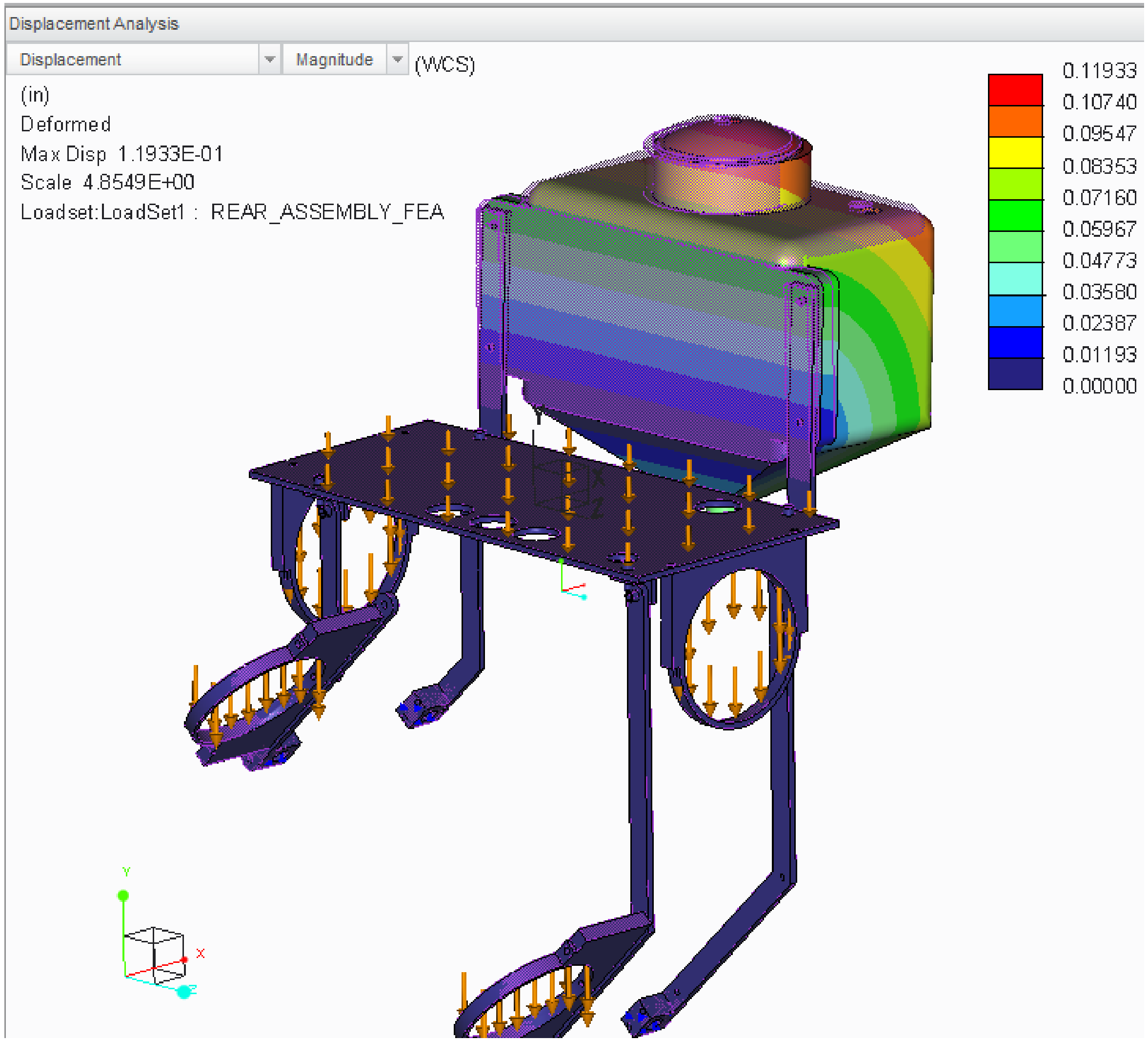


Finite Element Analysis

Final Design

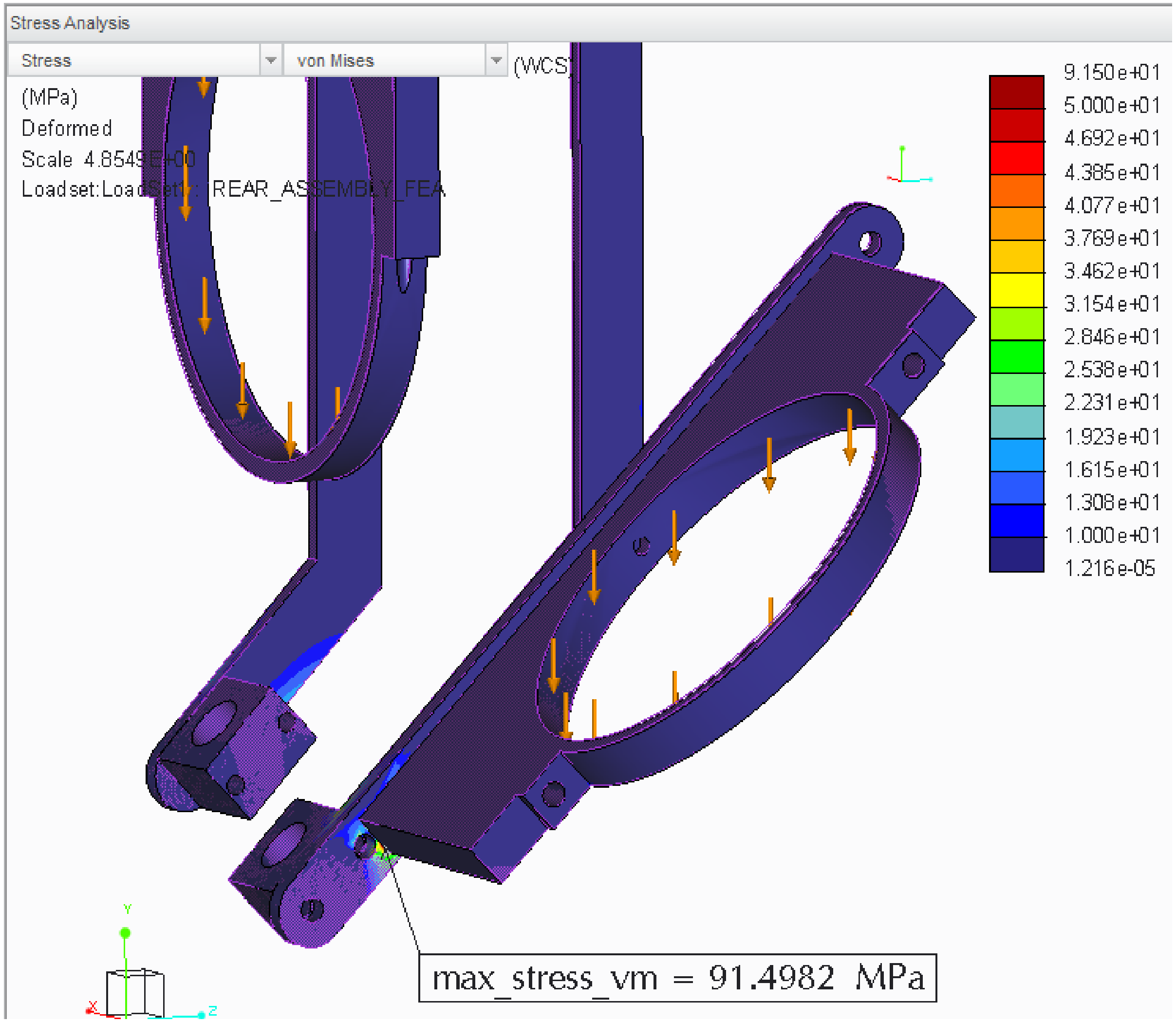
Material of Brackets

- (Connecting to frame) Steel
- (Accumulator rest, Component Plate) Aluminum

Yield Strength

- (Steel 1040) 415 MPa
- (Aluminum 2014-O) 414 MPa

Source: Mott R., (2014) Machine Elements in Mechanical Design, Fifth Ed.



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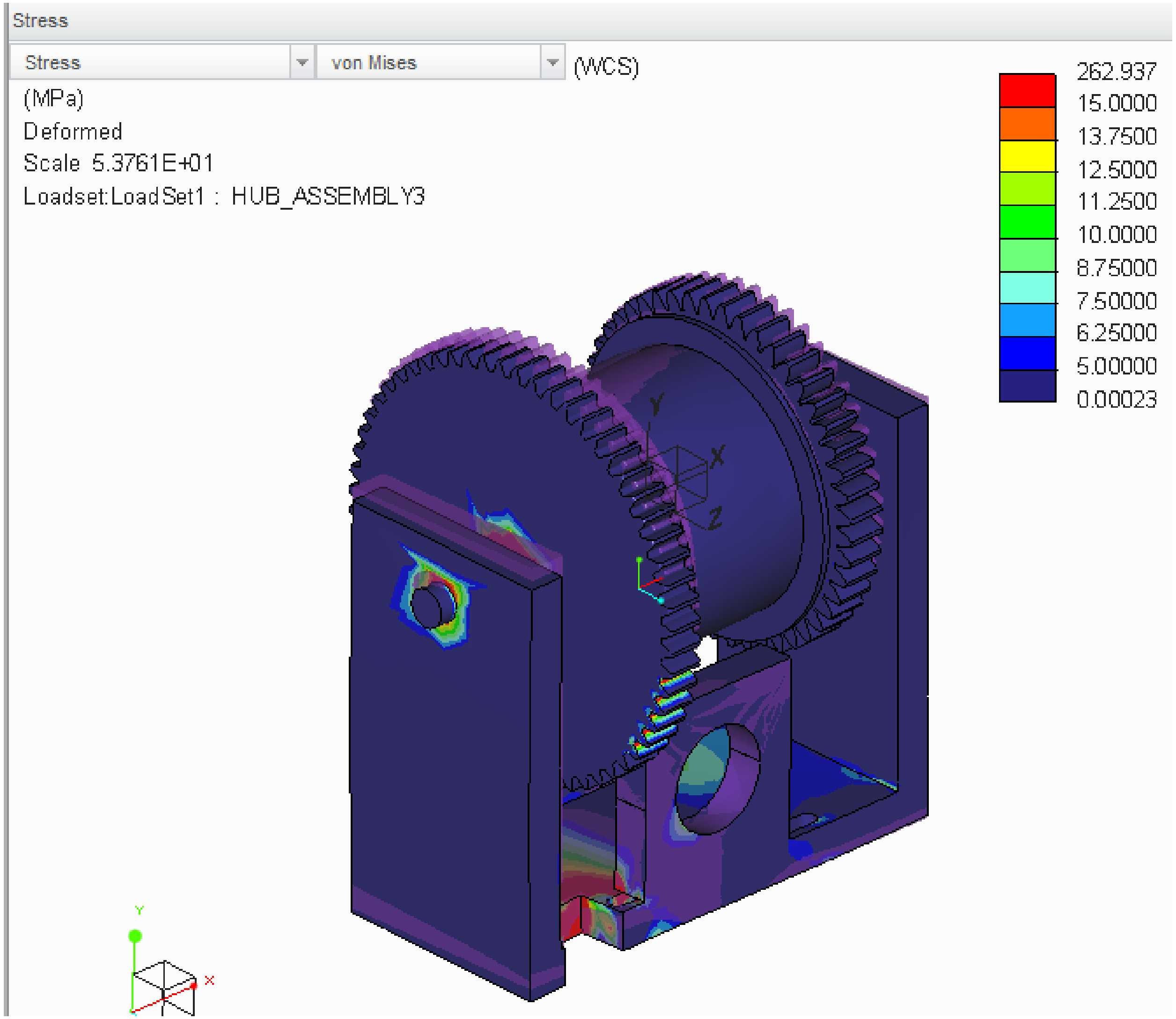

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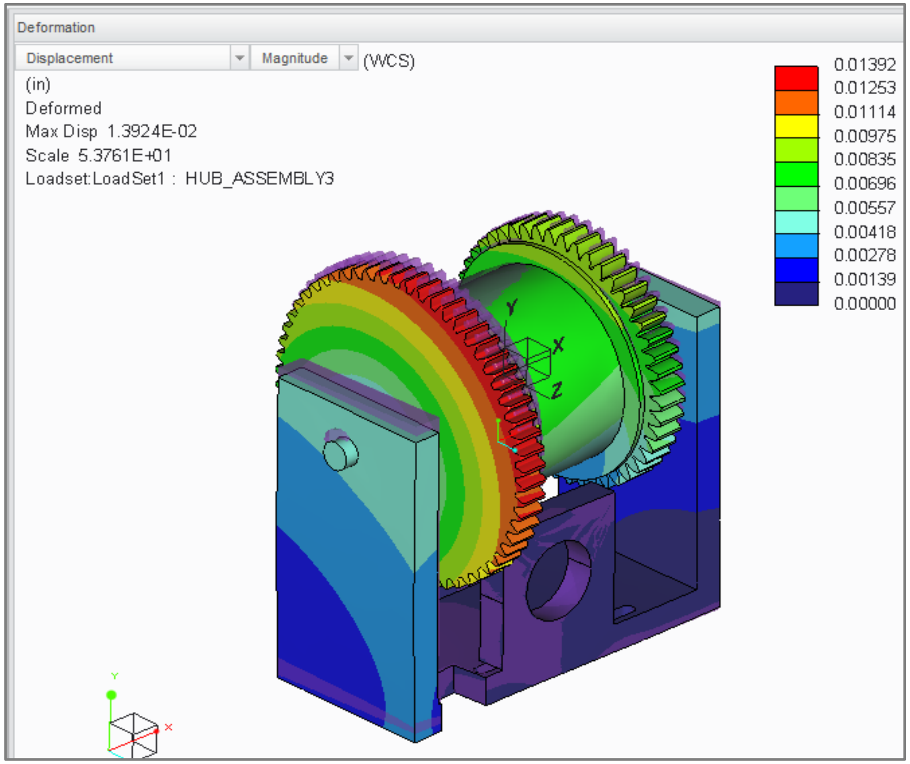

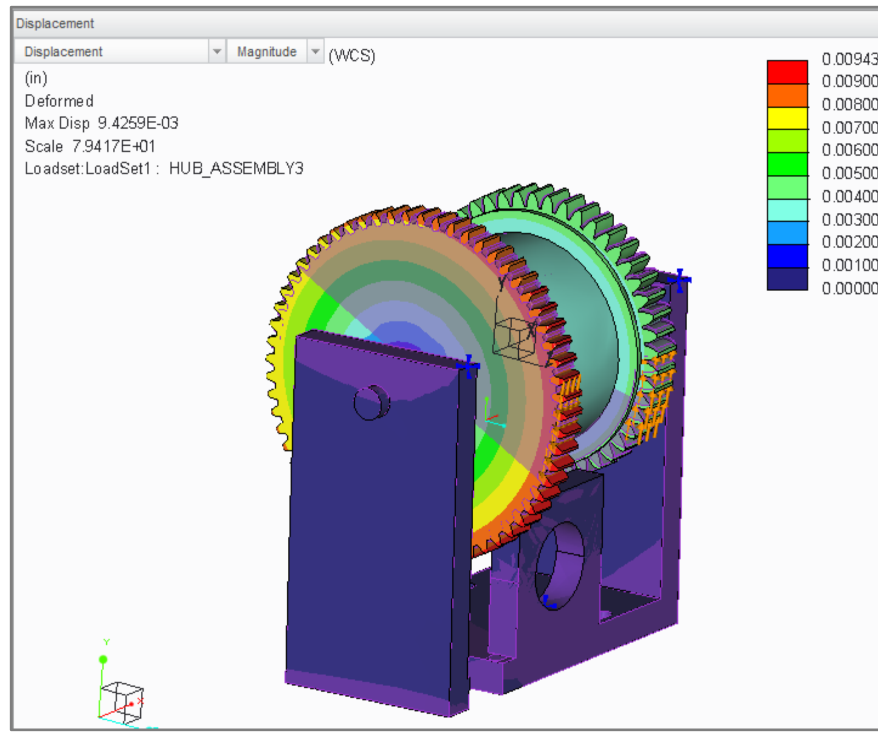

Cost Analysis (500 units)

Subsystem	Description	Part Cost	Labor Cost	Quantity Discount	New Part Cost	New Labor Cost
Hydraulic Components	Pumps/Motors, Accumulators, Hand pump, Reservoir	$3,573.96	$0.00	Bulk discount: 25%	$2,680.47	$0.00
Valves	Pressure relief valve, check vlave, proportional valve, directional control valve	$757.64	$0.00	Bulk discount: 25%	$568.23	$0.00
Bicycle Components	Bicycle frame	$478.99	$0.00	Bulk discount: 30%	$335.29	$0.00
Hydraulic Connections	Hose, fittings, adapters	$730.47	$0.00	Bulk discount: 30%	$511.33	$0.00
Gear Train	Front hub, rear hub, misc. gears	$665.22	$90.00	Bulk discount: 20%	$532.18	$0.00
Electronics	Control panel, power box, etc.	$250.98	$0.00	Bulk discount: 40%	$150.59	$0.00
Fabrication	misc. materials, aluminum and steel	$181.12	$1,770.00	Bulk discount: 35%	$117.73	$885.00
Misc. materials	bolts, nuts, screws	$88.43	$0.00	Bulk discount: 50%	$44.22	$0.00
Cost of Parts and Materials		$6,726.81			$4,940.03	
Cost of labor	Parts preparation		$1,860.00			$885.00
Cost of labor	Assembly		$360.00		Jig/fixture assembly and set up	$120.00
Total Cost			$8,946.81			$5,945.03
Percent Reduction						33.55%
Total Cost (500 units)						$2,972,514.50

Pump and Motor Testing

- Testing conducted at Parker Aerospace
- Due to nature of their business, unable to retain hard data
- Information learned on the function of our pump/motor:
  - For our application they have the ability to flow either direction
  - Case drain not needed

Accumulator Testing and Trial Runs

- One accumulator tested at a time – isolate any issues and reduce number of variables
  - First 2 runs = horizontal accumulator
  - Third run = angled accumulator
- Runs made in building (400m in length)
- Nitrogen pre-charge of 500 psi

Accumulator Testing and Trial Runs

- One final run with both accumulators in use was made outdoors – bike traveled ½ mile (~800 meters)

Run #1	
Distance (m)	PSI
0	2600
10	1600
100	1330
150	1150
200	900
300	810
400	720

Run #2	
Distance (m)	PSI
0	2600
10	1650
100	1350
150	1170
200	910
300	810
400	720

Run #3	
Distance (m)	PSI
0	2600
10	1620
100	1340
150	1160
200	900
300	810
400	720

Post-Race Notes

- Bike arrived damaged – flat tire
- Parts of the hydraulic circuit malfunctioned before the efficiency race – adapt circuit to isolate section

Lessons Learned and Conclusions

- Design refinement cycle
  - Test, analyze, improve, repeat
- Project planning and time management
- Have rational and reasoning behind every decision
- More background knowledge on major components needed

Questions?

We want to thank you for your time from the WMU 2015-2016 Chainless Challenge Team

Go Broncos!!