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DOE Project DE-FC26-04NT42270: Systematic Engine Uprate Technology Development and Deployment through Increased Torque

“Engine Uprates”

DOE/ NETL Project Kickoff
April 21, 2005

Outline

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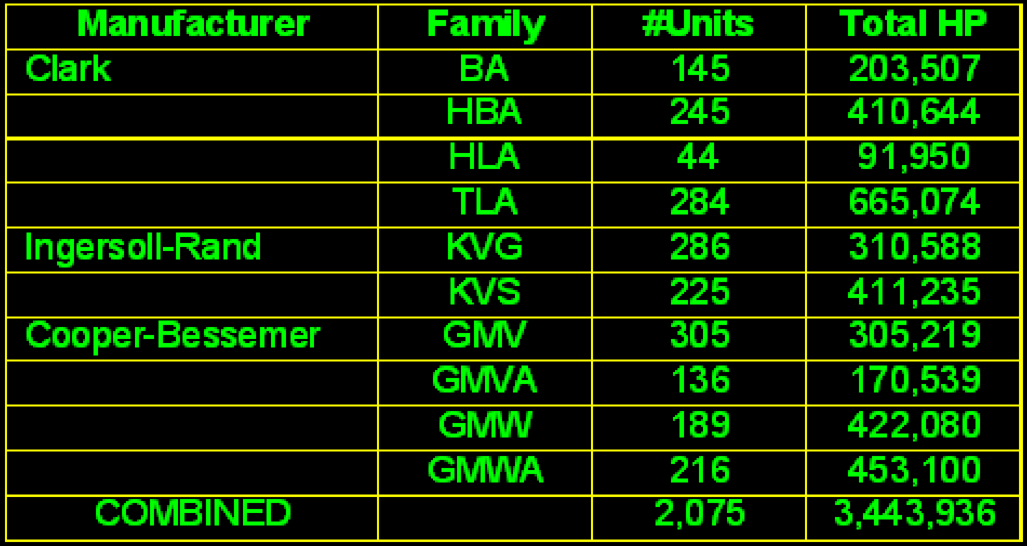
- Executive Summary (Ted)
- Previous Work done with GTI Funds (Dan)
- DOE Year 1 Results To-Date (Dan)
- Planned Research Activities (Dan)

Engine Uprates: Motivation

"The overall objective of this project is to develop new engine up-rate technologies that will be applicable to a large inventory of existing pipeline compressor units for the purpose of increasing pipeline throughput with the same footprint of existing facilities"

- Increase Output by 10%
- Target Cost ~ $500/HP



Manufacturer	Family	#Units	Total HP
Clark	BA	145	203,507
	HBA	245	410,644
	HLA	44	91,950
	TLA	284	665,074
Ingersoll-Rand	KVG	286	310,588
	KVS	225	411,235
Cooper-Bessemer	GMV	305	305,219
	GMVA	136	170,539
	GMW	189	422,080
	GMWA	216	453,100
COMBINED		2,075	3,443,936

Objectives by Year

- Year 1: Laboratory Demonstration of Candidate Technologies
  - Demonstrate that the technologies developed during the background research phase to achieve the performance targets under controlled, laboratory conditions and using the Engines and Energy Conversion Laboratory's (EECL's) Clark TLA research engine.

- Year 2 (Phase 2): Demonstration of Optimal Technologies
  - Demonstrate that the technologies tested under phase 1 can migrate to an operating engine in pipeline service with similar, or better, performance and that the durability of the retrofit equipment will be acceptable.

Issues to Keep in Balance

- OEM Business Strategy
  - Dresser-Rand
  - Cooper Compression
- Enabling Technologies
- Air Emissions Permits
- FERC Capacity Certification

Project Team

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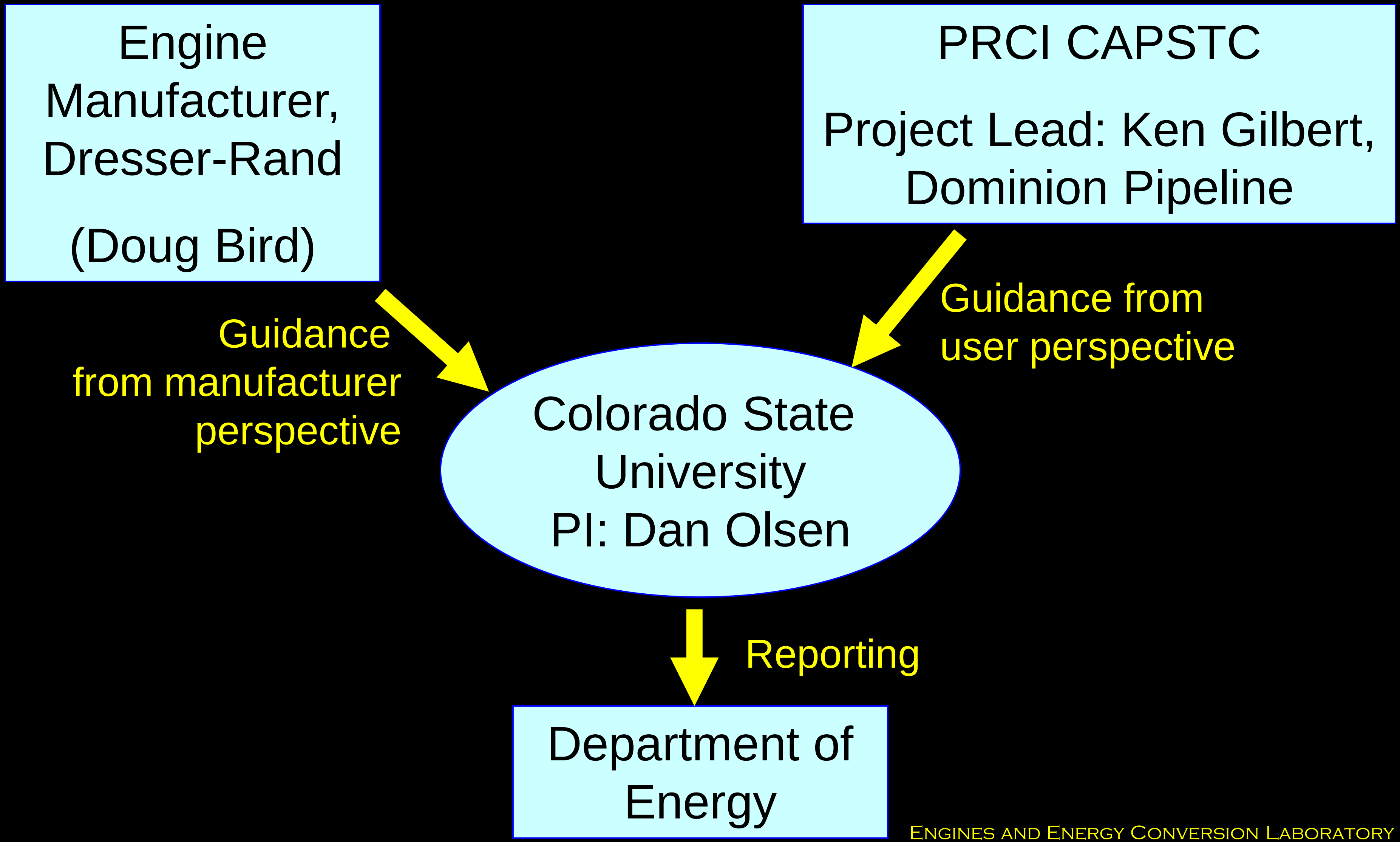

Engine Manufacturer, Dresser-Rand

(Doug Bird)

Guidance from manufacturer perspective

PRCI CAPSTC

Project Lead: Ken Gilbert, Dominion Pipeline

Guidance from user perspective

Colorado State University
PI: Dan Olsen

Reporting

Department of Energy

Year 1 Project Schedule

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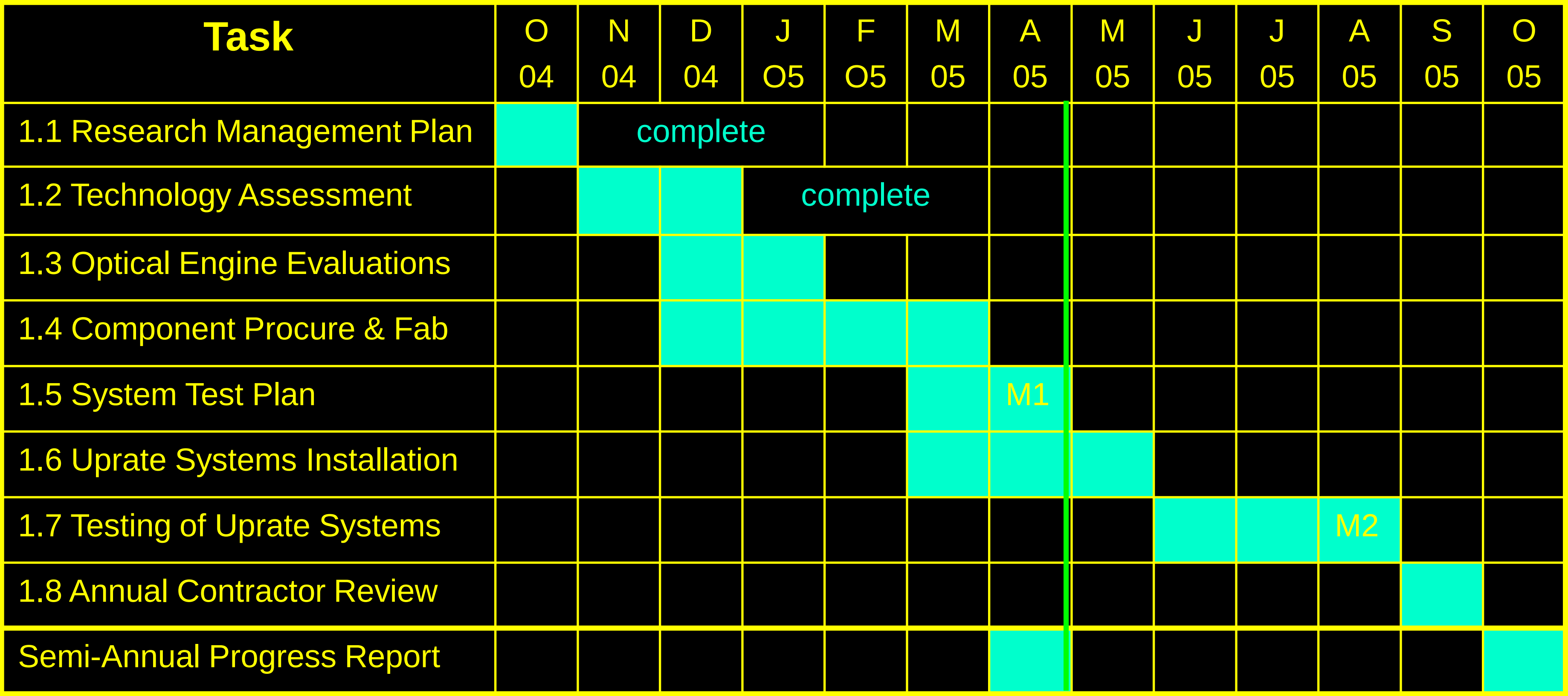
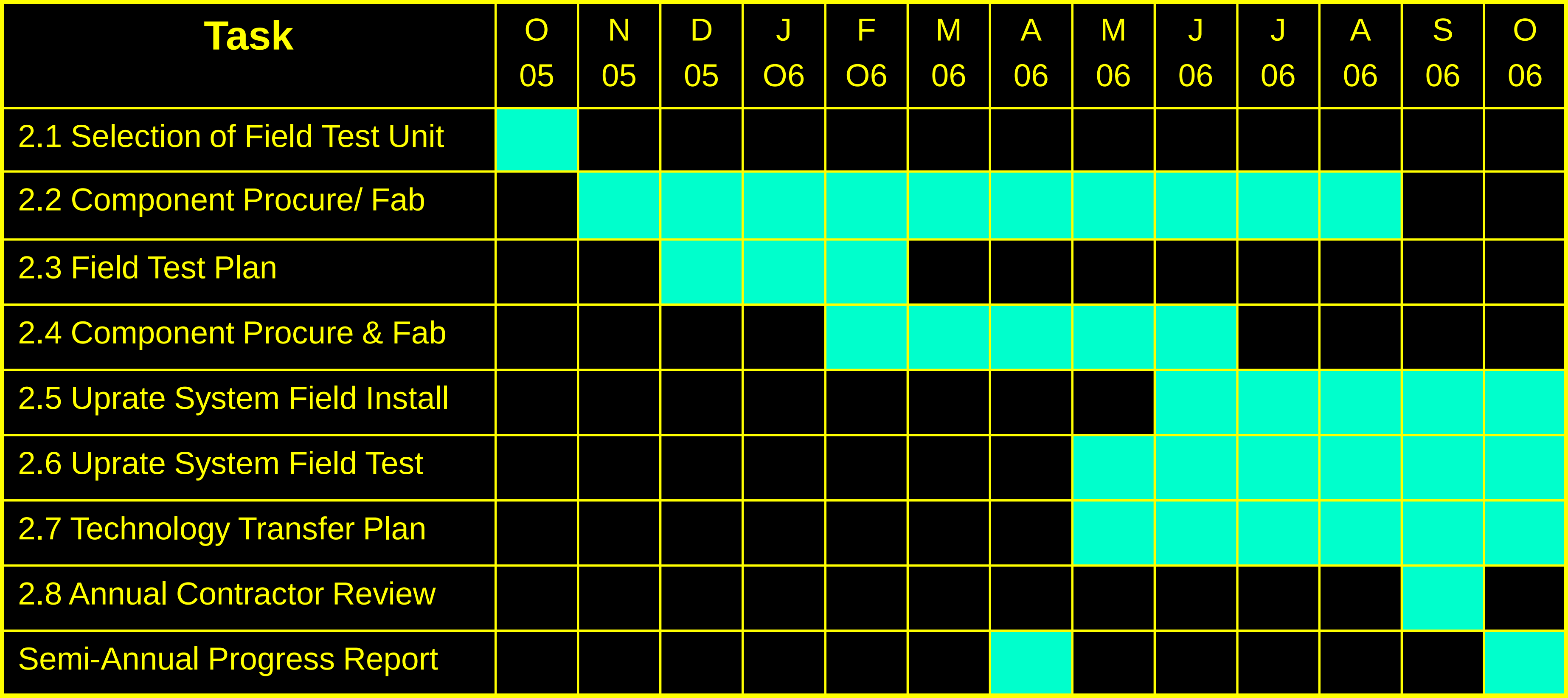


Task	O 04	N 04	D 04	J O5	F O5	M 05	A 05	M 05	J 05	J 05	A 05	S 05	O 05
1.1 Research Management Plan	■	complete											
1.2 Technology Assessment		■	■	complete									
1.3 Optical Engine Evaluations			■	■									
1.4 Component Procure & Fab			■	■	■	■							
1.5 System Test Plan						■	■ M1						
1.6 Uprate Systems Installation						■	■	■					
1.7 Testing of Uprate Systems									■	■	■ M2		
1.8 Annual Contractor Review												■	
Semi-Annual Progress Report							■						■

Year 2 Project Schedule



Task	O 05	N 05	D 05	J O6	F O6	M 06	A 06	M 06	J 06	J 06	A 06	S 06	O 06
2.1 Selection of Field Test Unit	■												
2.2 Component Procure/ Fab		■	■	■	■	■	■	■	■	■	■		
2.3 Field Test Plan			■	■	■								
2.4 Component Procure & Fab					■	■	■	■	■				
2.5 Uprate System Field Install									■	■	■	■	■
2.6 Uprate System Field Test								■	■	■	■	■	■
2.7 Technology Transfer Plan								■	■	■	■	■	■
2.8 Annual Contractor Review												■	
Semi-Annual Progress Report							■						■

Funding Sources

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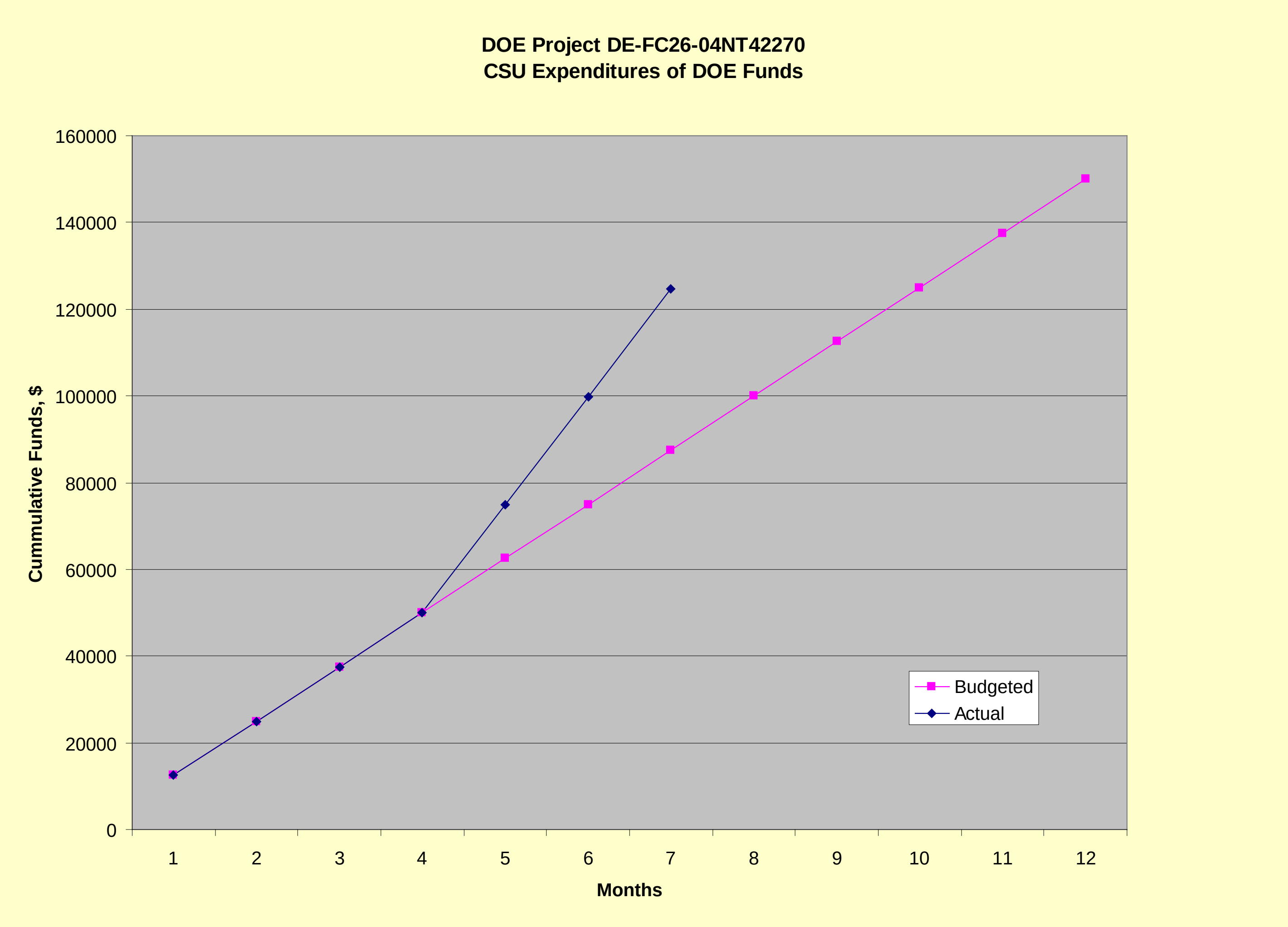
	2003				**2004**				**2005**				**2006**			
GTI Only $240,000 (FERC funds)	🟪	🟪	🟪	🟪	🟪	🟪	🟪									
GTI Cost-Share $100,000 (FERC funds)								1	1							
PRCI $160,000 (Industry funds)												2	2	2	2	
DOE $150,000 (Yr 1) $250,000 (Yr 2)								1	1	1	1	2	2	2	2	

Expenditures



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Identify Potential Engines: Engine Candidates

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Desired Engine Candidate Requirements

- BMEP vs. Quantity

Want to find engines with:

- Low BMEP
- Significant Installed Base
- 2-Stroke

Identify Potential Engines: Engine Uprates Survey Table

Manufacturer	Family	#Units	Total HP	Type (2/4 stroke)	Cyl. Dims.	Cylinder Configurations	Air Delivery	BMEP
Clark	BA	145	203507	2	17x17	5,6,8,10	Piston Scavenged	68.3
	HBA	245	410644	2	17x17	5,6,8,10	Piston Scavenged	75.3
	HLA	44	91950	2	17x19	5,6,8,10	Nat. Asp.	76.5
	TLA	284	665074	2	17x19	5,6,8,10	Turbocharged	103.3
Ingersoll-Rand	KVG	286	310588	4	15.25x18	6,8,10,12	Nat. Asp.	80.34
	KVS	225	411235	4	15.25x18	6,8,10,12	Elliott Turbo.	121.7
Cooper-Bessemer	GMV	305	305219	2	14x14	4,6,8,10	Piston Scavenged	61.3
	GMVA	136	170539	2	14x14	4,6,8,10,12	Blower	79.2-84.3
	GMW	189	422080	2	18x20	6,8,10	Blower	74.5
	GMWA	216	453100	2	18x20	6,8,10,12	Blower	77.5

Identify Potential Engines: Target Engines

Based upon the engine survey table, the following engines meet the requirements:

- Clark HBA
- Clark TLA
- Cooper-Bessemer GMV series

Technical Considerations: Potential Technologies

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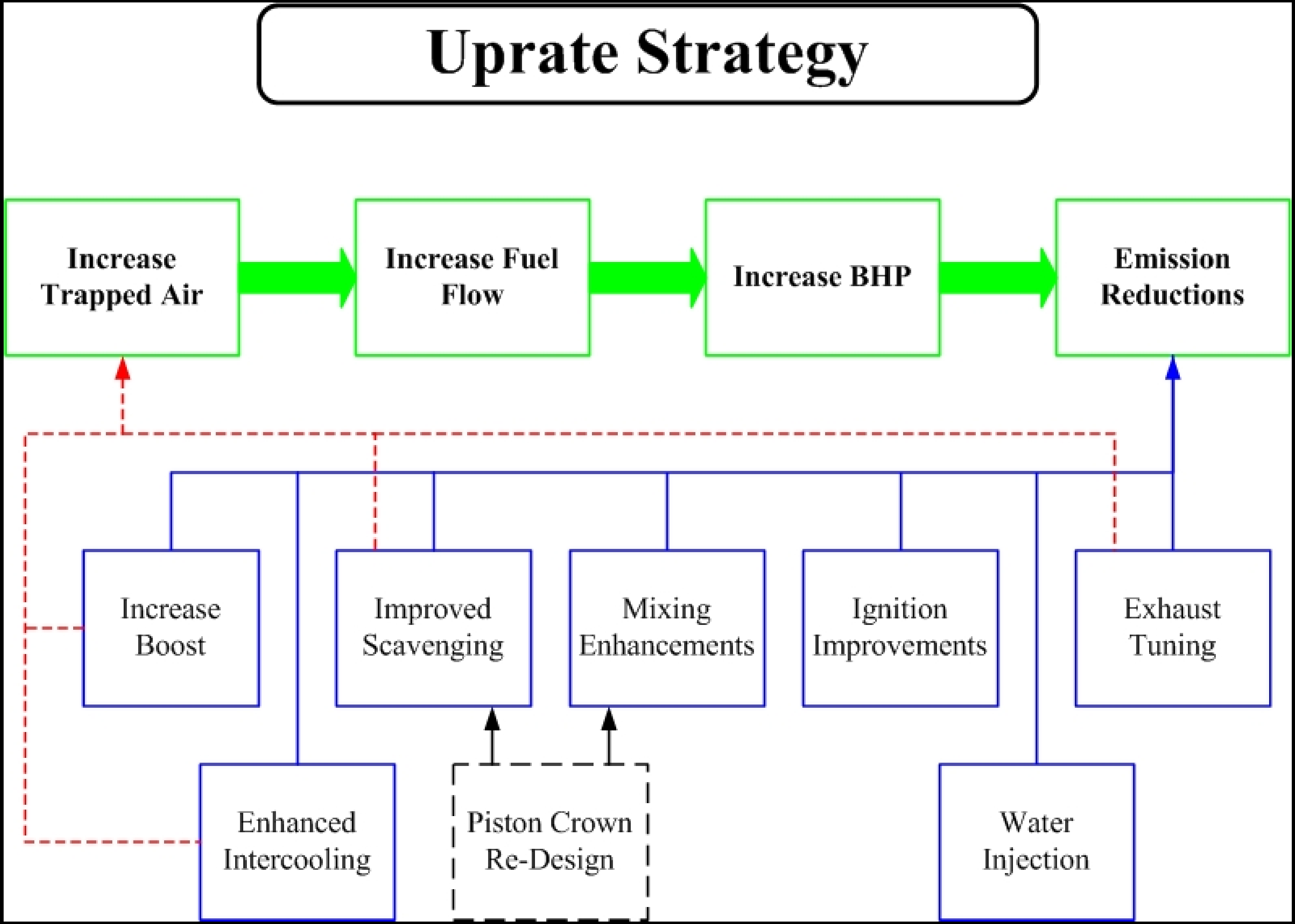
- Turbocharger Upgrade or Installation
- High Pressure Fuel Injection
- Micro Pilot Injection
- Pre-Combustion Chambers
- Intercooling
- Piston Crown Re-design
- Exhaust Tuning

Block Diagram



Uprate Strategy

Increase Trapped Air

Increase Fuel Flow

Increase BHP

Emission Reductions

Increase Boost

Improved Scavenging

Mixing Enhancements

Ignition Improvements

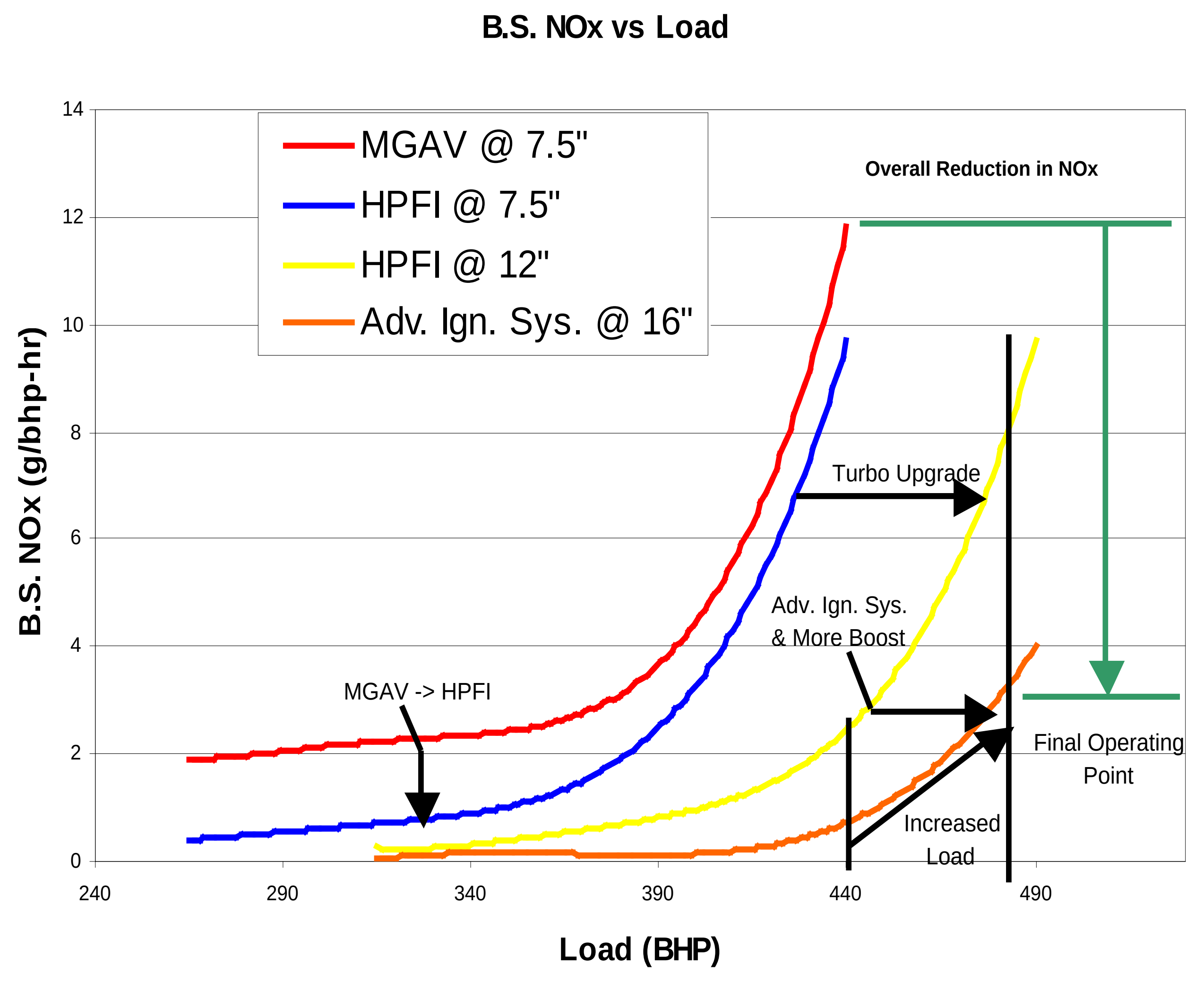
Exhaust Tuning

Enhanced Intercooling

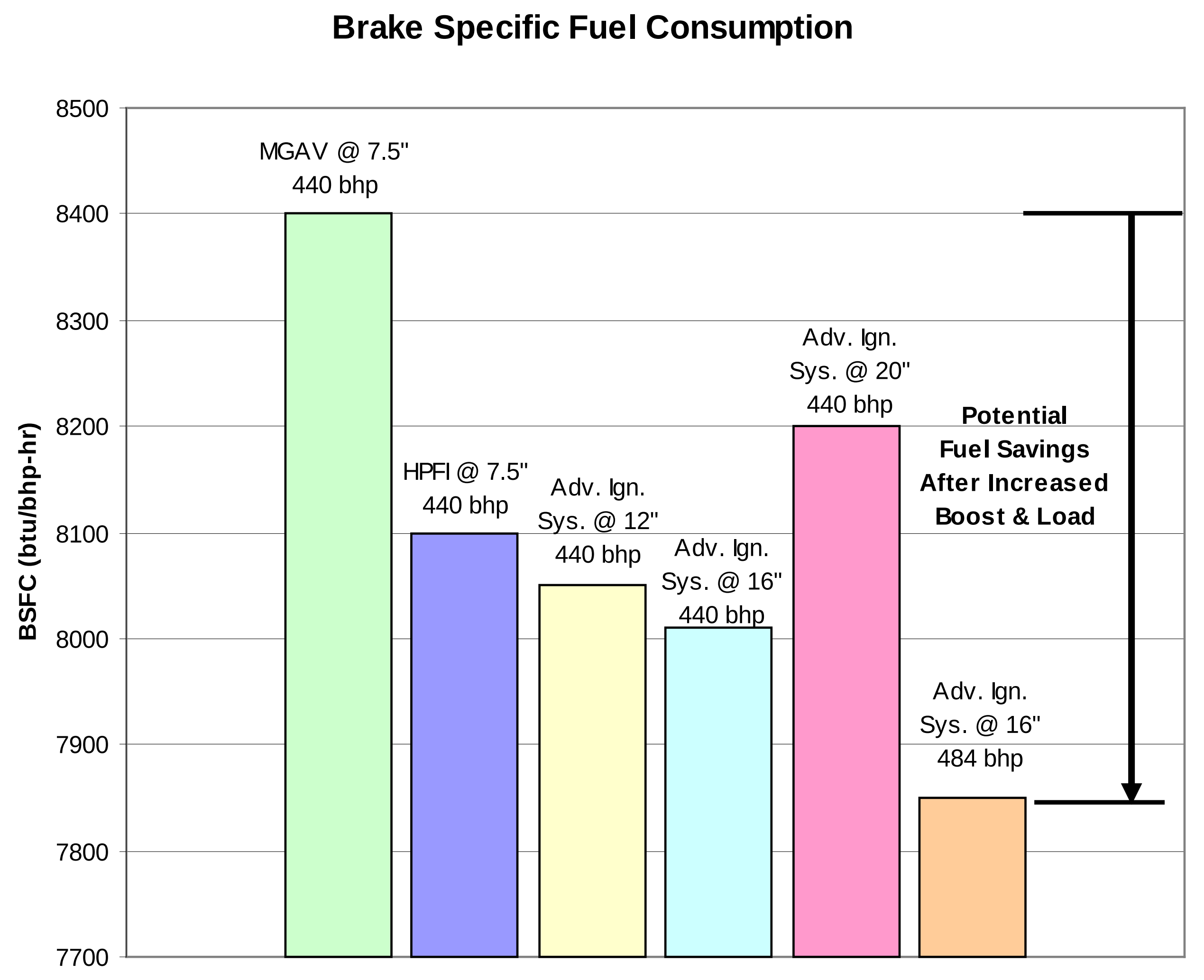
Piston Crown Re-Design

Water Injection

Projected Reduction In NOx After Uprating Methods



Projected Fuel Savings with Uprating Methods



The Effect of Combustion Stabilization

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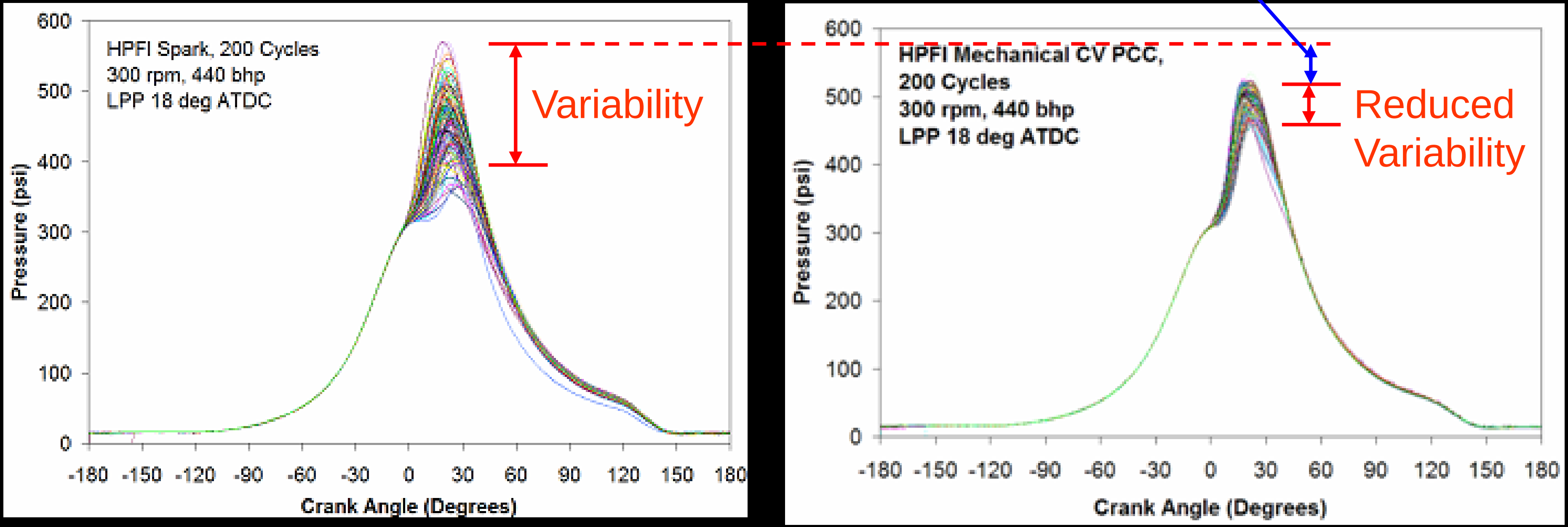
Potential increase in average peak pressure without increasing maximum peak pressure



Combustion stabilization through enhanced ignition

Micro Pilot Ignition System

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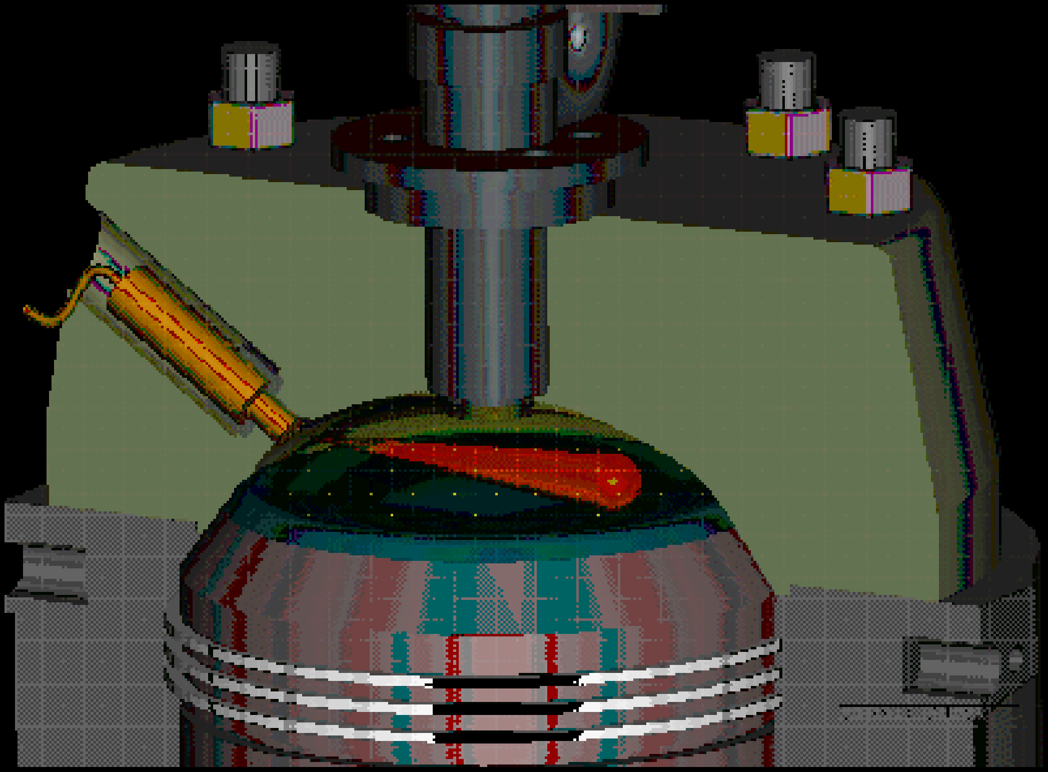
Using a micro-liter quantity of a compression ignitable pilot fuel

as the ignition

source



Micro Pilot Ignition System

Success with Cooper-Bessemer GMV

- No Misfires
- Lower THC
- Lower BSFC
- Achieved <1% pilot fuel energy
- Worked with stock compression ratio

Micro Pilot Ignition System

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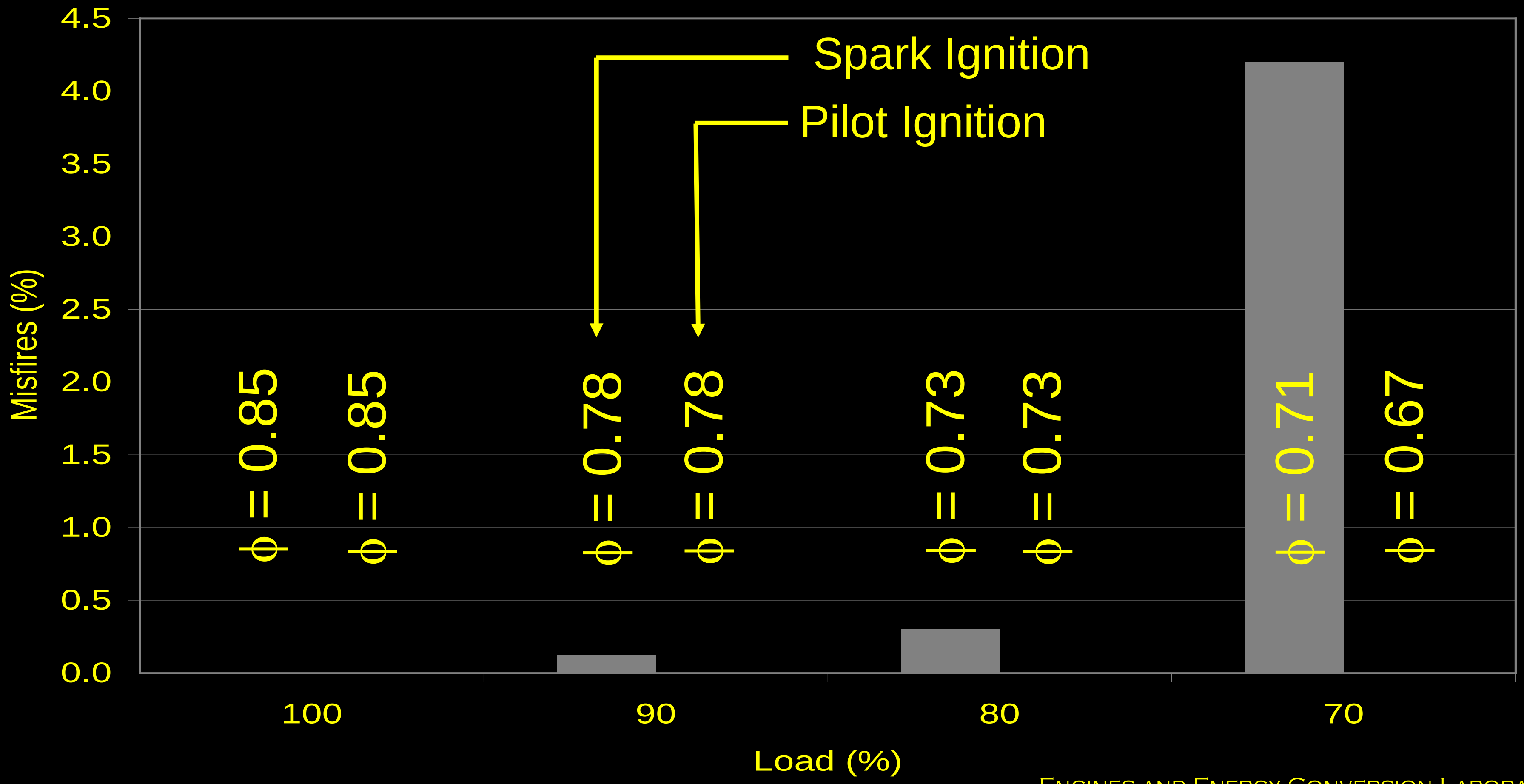
Misfire Elimination



Micro Pilot Ignition System

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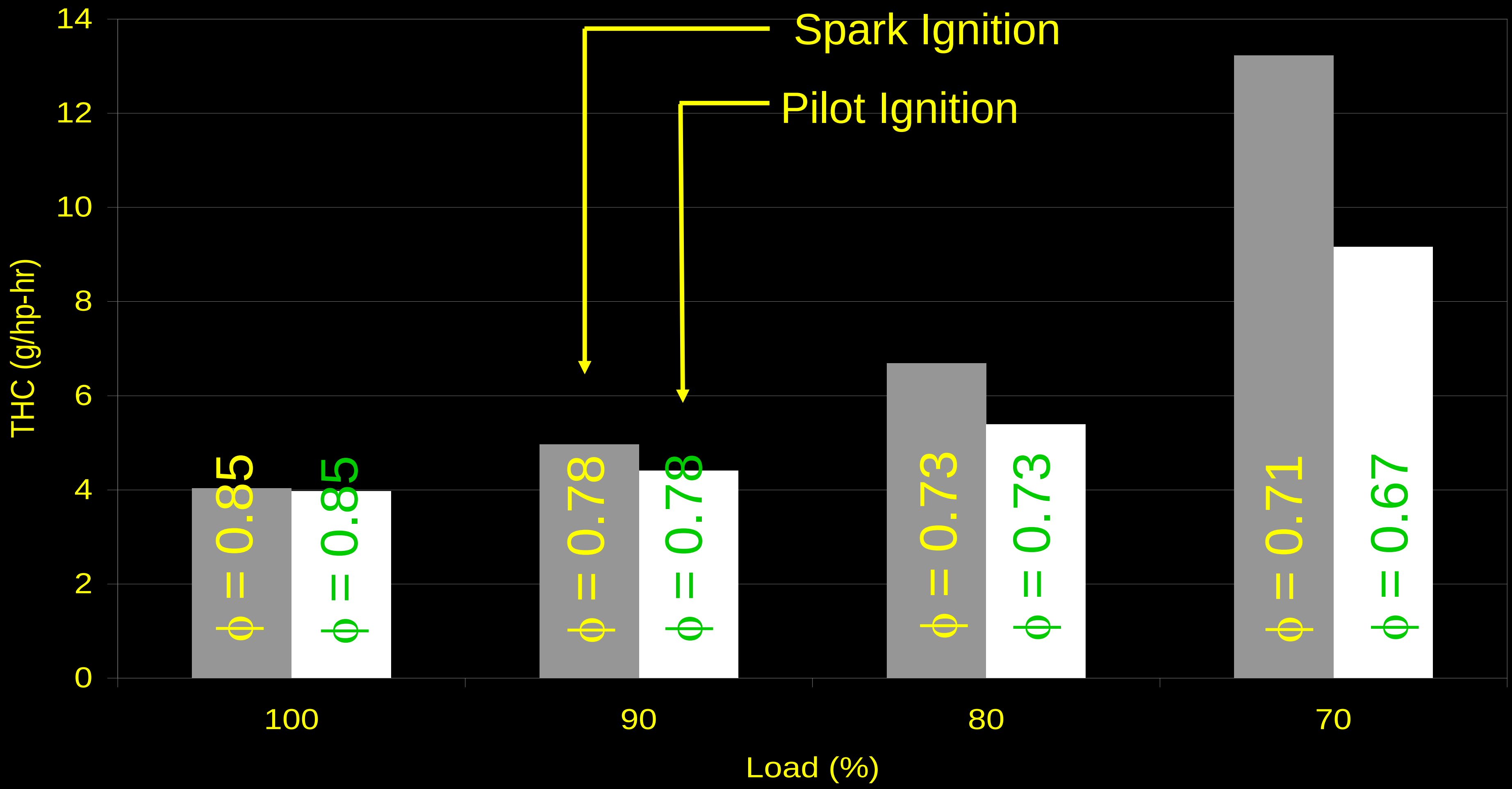
THC Reduction



Micro Pilot Ignition System

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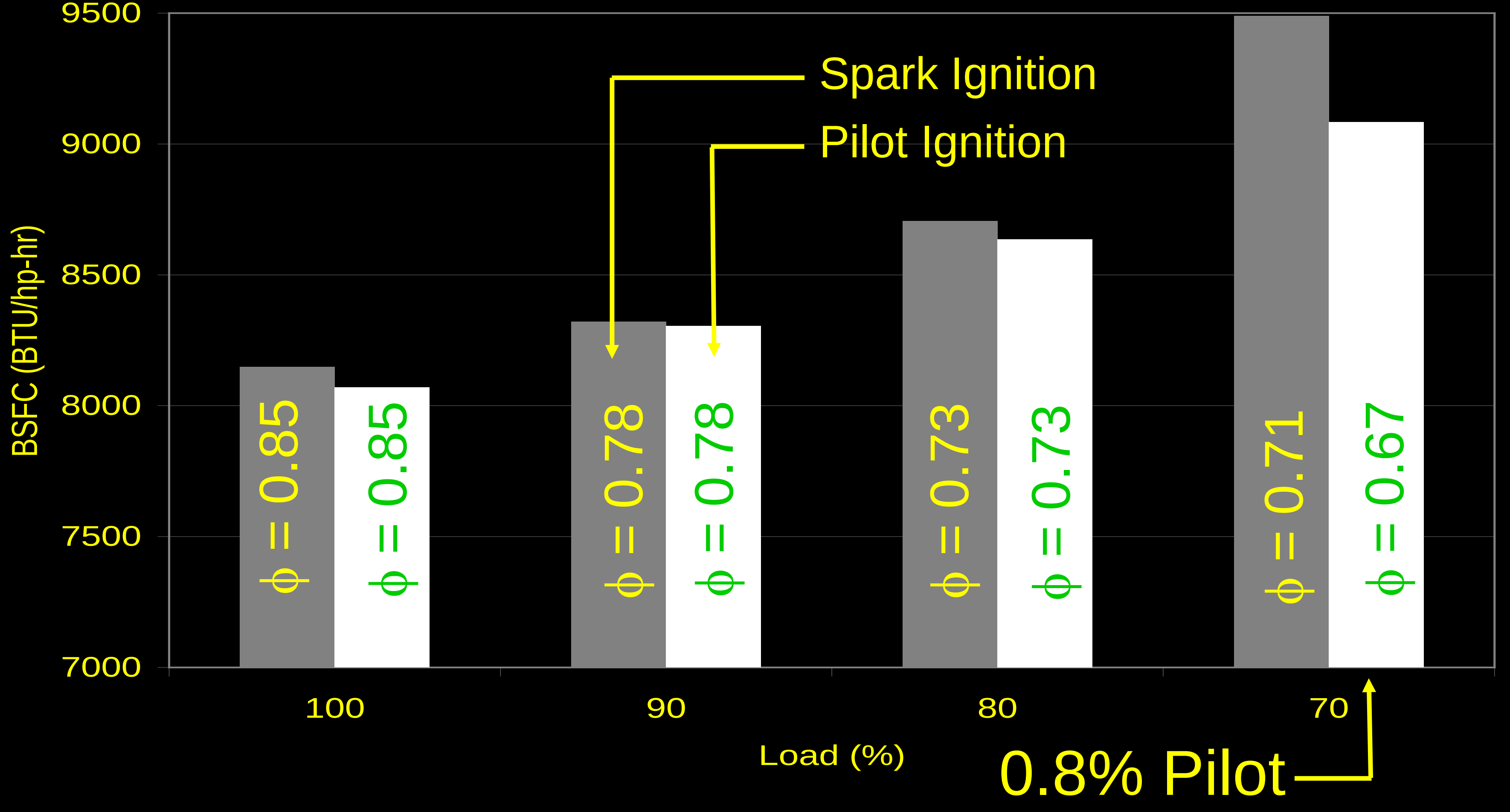
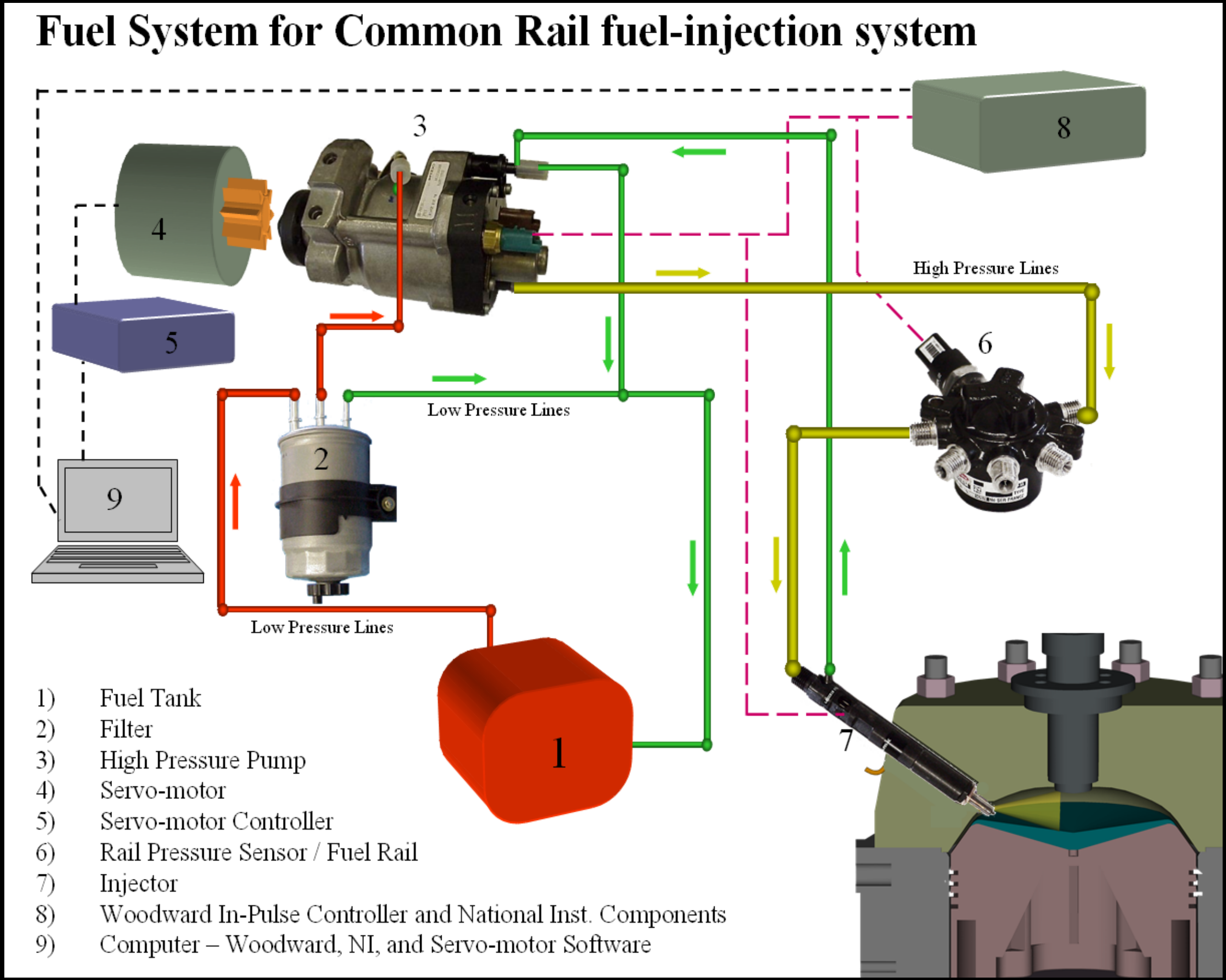
BSFC Reduction



Micro Pilot Ignition System

Currently, key components are provided by Woodward and Delphi

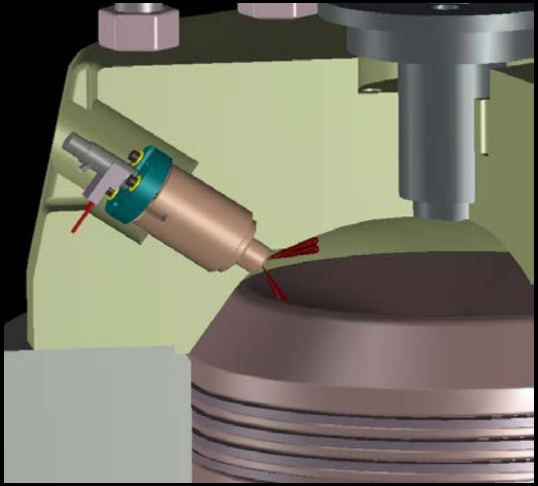


Fuel System for Common Rail fuel-injection system

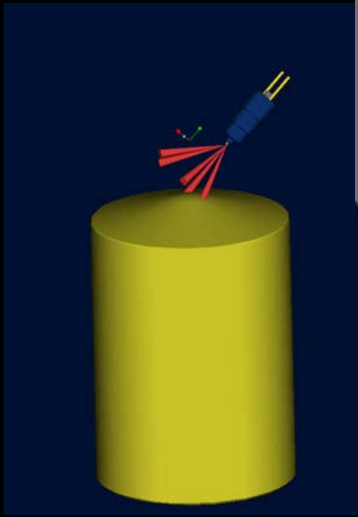
1) Fuel Tank
2) Filter
3) High Pressure Pump
4) Servo-motor
5) Servo-motor Controller
6) Rail Pressure Sensor / Fuel Rail
7) Injector
8) Woodward In-Pulse Controller and National Inst. Components
9) Computer – Woodward, NI, and Servo-motor Software

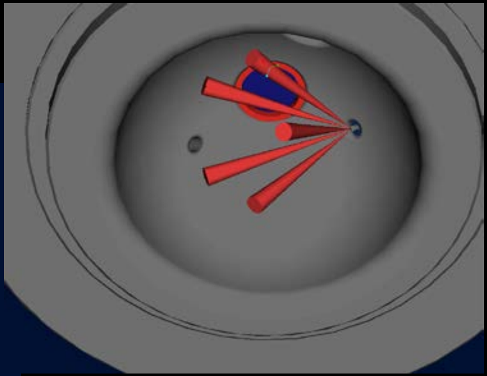
Micro Pilot Ignition System

The current injectors used will work better for the Clark engine than for the GMV



Impinging Sprays

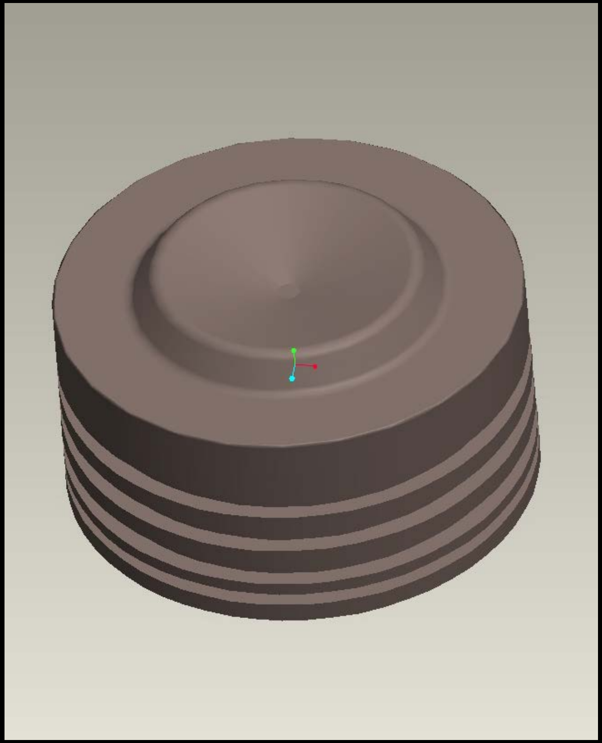


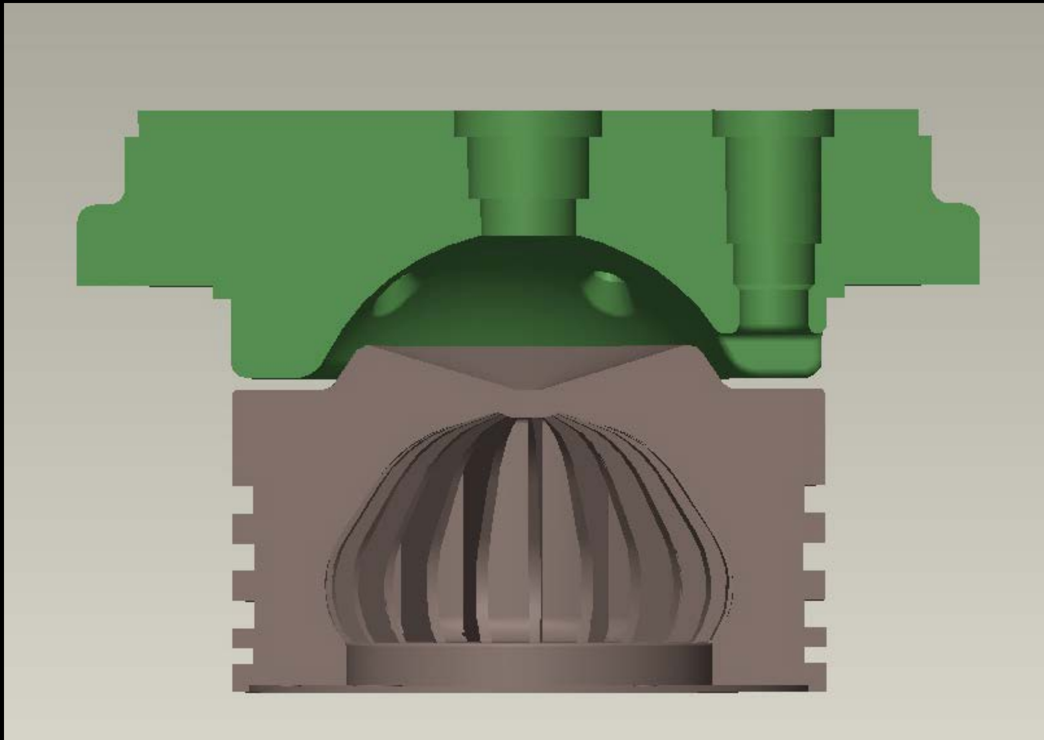


No Impingement

This was shown to reduce pilot fuel quantity with custom fuel injector testing

Clark TLA Piston Crown Re-Design Example



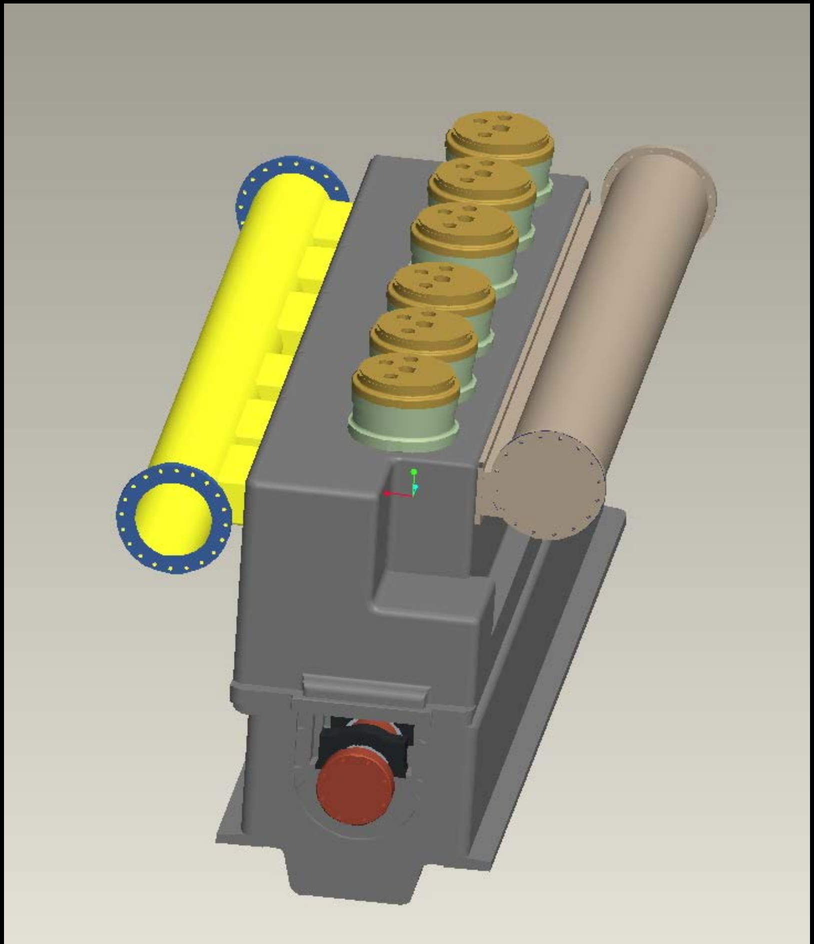


Clark TLA Exhaust Tuning Example

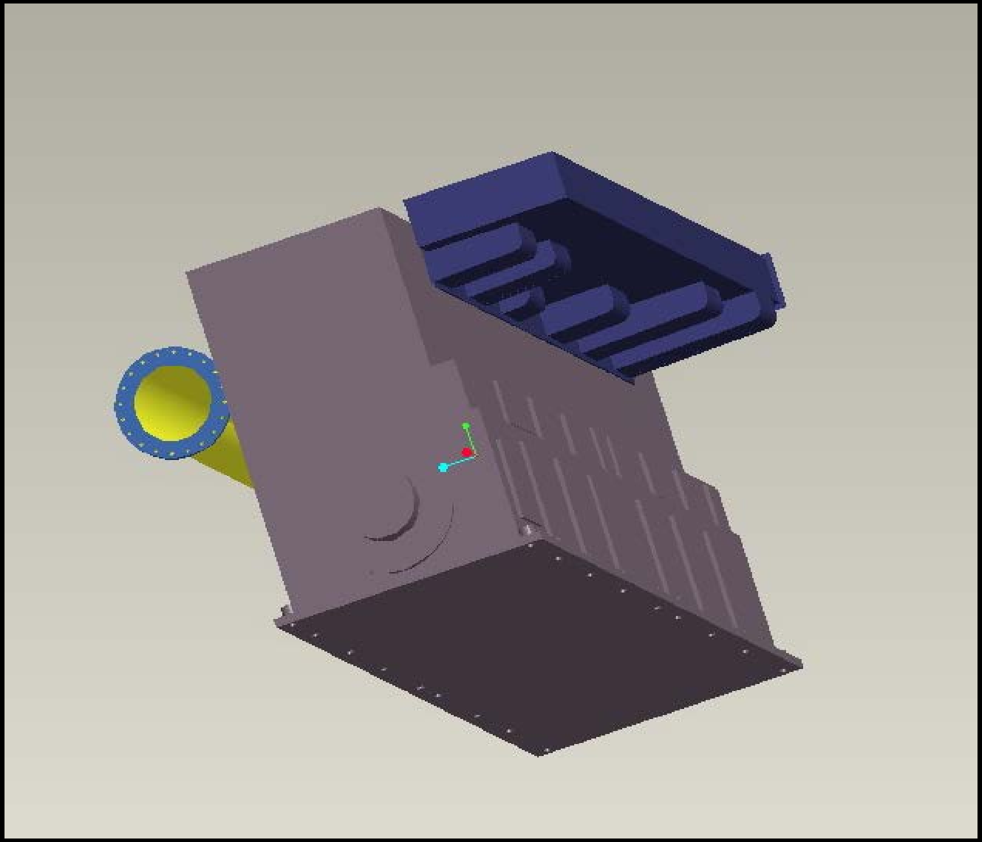
- Developed using Ricardo WAVE
  - Engine simulation software
  - Models compressible flow effects (1-D)
  - Computes emissions
  - 2-zone combustion model
- Engine is first modeled under nominal operating conditions, matching efficiency, cylinder pressure profile, NOx emissions, and other parameters
- Manifold is optimized using 7 variable Design of Experiments technique, adapted for this application

Tuned Exhaust Manifold for Clark TLA Engine

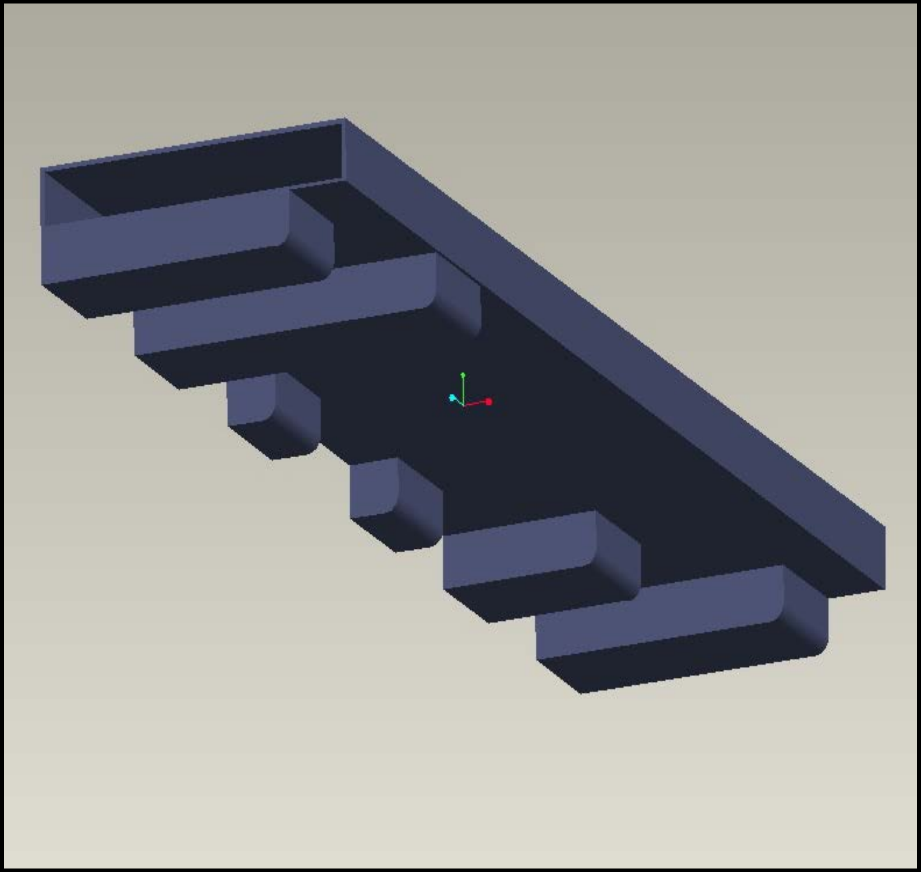
Original Exhaust Manifold

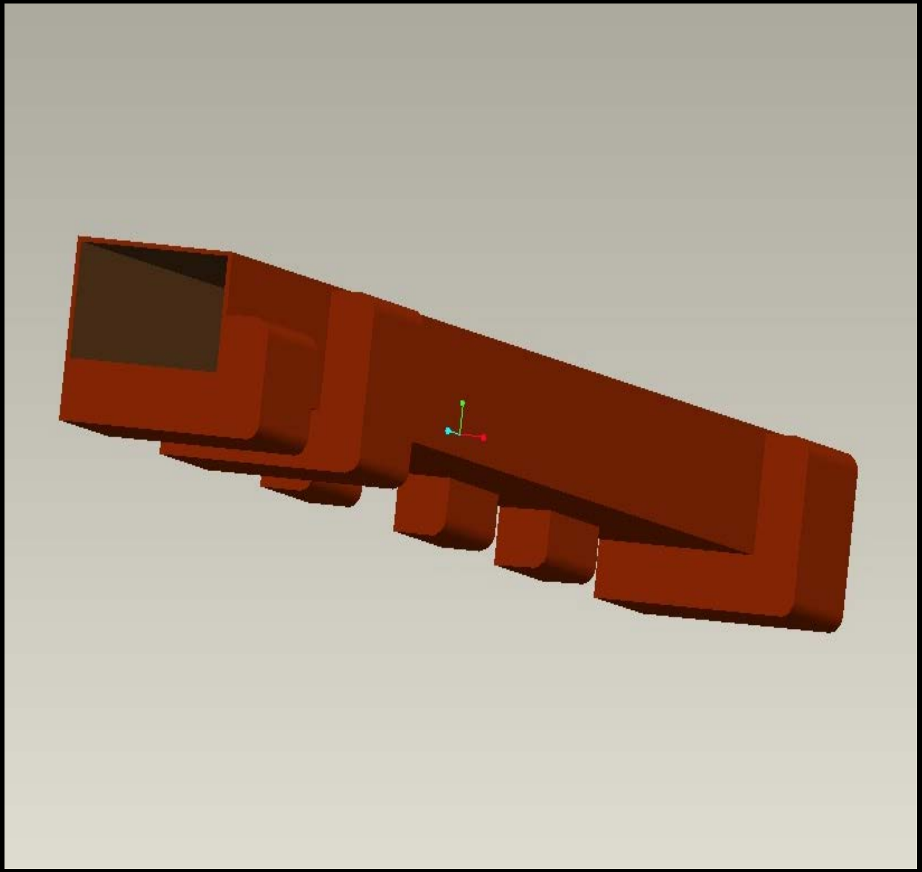


New Exhaust Manifold Design



Tuned Exhaust Manifold for Clark TLA Engine



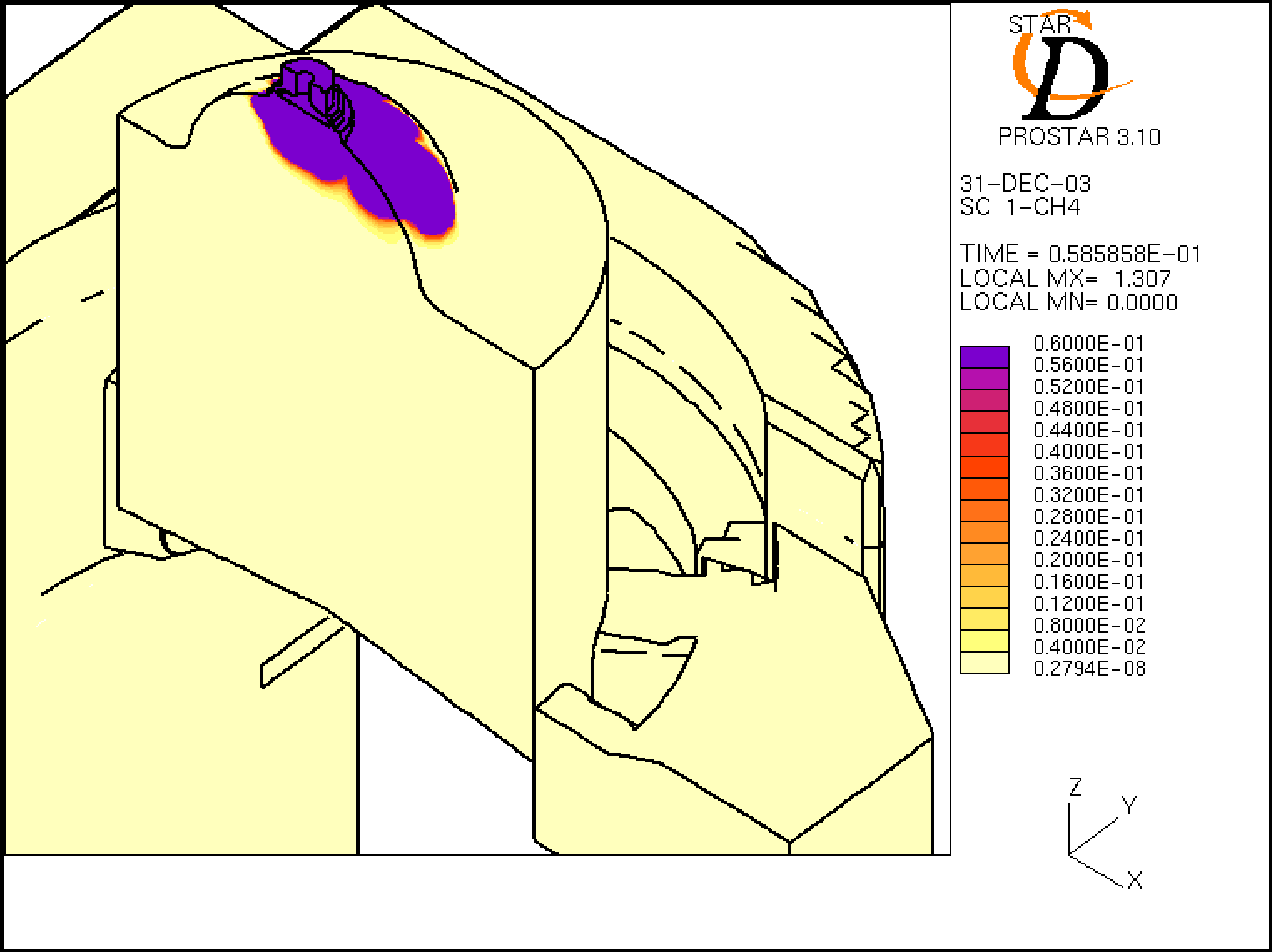


Tuned Exhaust Results

Parameters	Nominal	Optimized	Modified
Delivery Ratio	1.771	1.777	1.77
Scavenging Efficiency	0.87	0.871	0.869
Trapping Efficiency	0.491	0.49	0.491
IMEP (psi)	120.3	120.3	121.4
Peak Pressure (psi)	752.7	765.8	758.6
Location of PP (CA)	18.01	18.02	17.97
Brake Power (hp)	2000	2000	2020
BMEP (psi)	102	102	103.1
Mass Flow of Fresh Air (lb/hr)	34580	35640	35090
Trapped Equivalence Ratio	0.7259	0.7016	0.7212
Fuel (g)	3.275	3.23	3.275
NOx (g/bkW-hr)	12.81	8.45	10.59

- The first optimized case produced NO_x reduction of 34%
- The modified optimized case produced NO_x reduction of 17.3%

CFD Modeling of D-R Research Engine, K5X



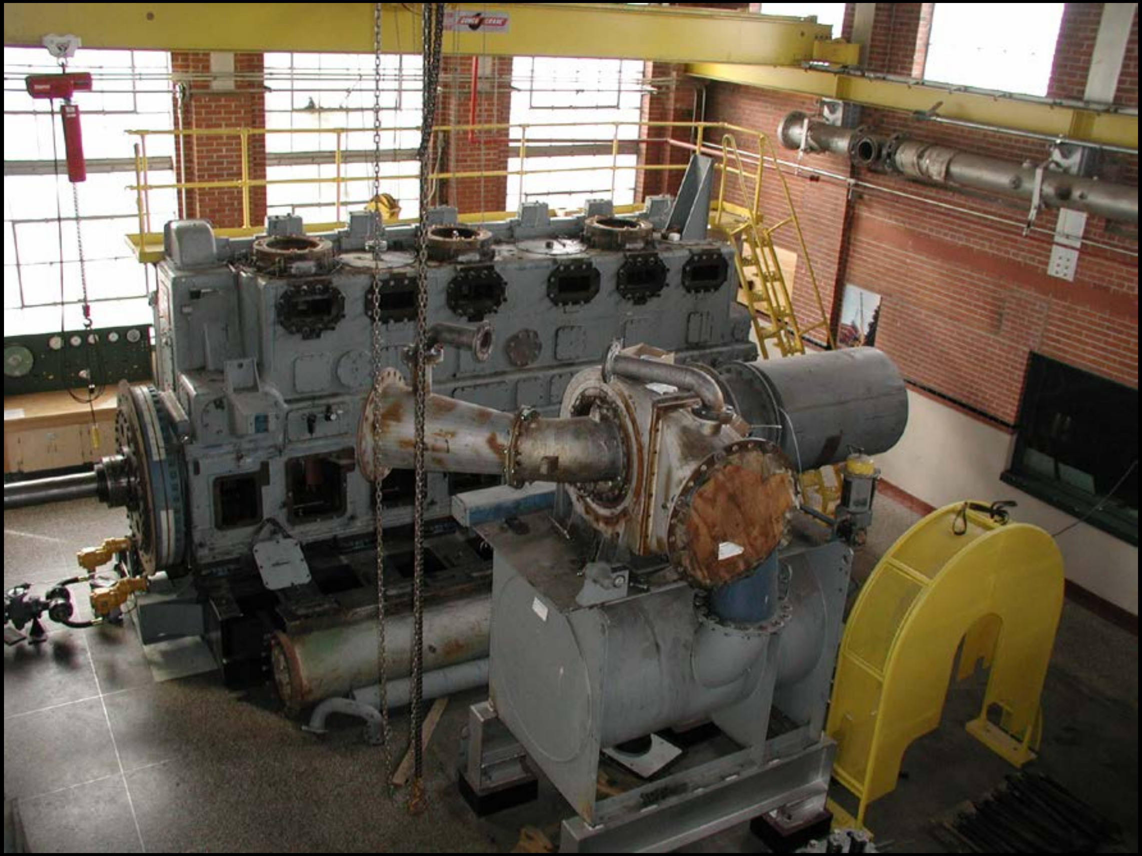
Cost Analysis

- Project target cost was to achieve <25% of new unit cost
- New unit (engine & compressor) with installation is estimated at $2,000/HP
- Cost reductions are thought to be attainable by use of a single installation contractor (example assumed three separate contractors)

Engine Uprate Case Study for Clark TLA-6		
Item Description	Cost for 200 BHP (10%) Increase	Cost for 500 BHP (25%) Increase
Turbocharger upgrade	$40,000	$40,000
HPFI hardware/installation	$150,000	$150,000
Pilot injection hardware	$14,000	$14,000
Pilot injection installation	$50,100	$50,100
Total Cost	$254,100	$254,100
Total Cost/HP	**$1,271**	**$508**
New unit cost/HP	$2,000	$2,000
Target Cost	$500	$500

EECL’s Clark TLA Engine – Donated by Dresser-Rand

- Currently being modified from 3-cylinder to 6-cylinder configuration



Engine Specific Uprate Strategy

Engine Uprates Technique Table

Manufacturer	Family	Type (2/4 stroke)	Original Air Delivery Method	BMEP	Enhanced Mixing	Improved Air Delivery	Improved Ignition	Exhaust Tuning
Clark	BA	2	Piston Scavenged	68.3	HPFI	TC	X[1]	TBD
	HBA	2	Piston Scavenged	75.3	HPFI	TC	X[1]	TBD
	HLA	2	Piston Scavenged	76.5	HPFI	TC	X[1]	TBD
	TLA	2	Turbocharged	103.3	HPFI	TU	X[1]	X
	K5X	2	Turbocharged	129.2	N/A			
Ingersoll-Rand	KVG	4	Nat. Asp.	80.34	HPFI	TC	X[1]	TBD
Cooper-Bessemer	GMV	2	Piston Scavenged	61.3	HPFI	TC	X[1]	TBD
	GMVA	2	Blower	79.2-84.3	HPFI	TC	X[1]	TBD
	GMW	2	Blower	74.5	HPFI	TC	X[1]	TBD
	GMWA	2	Blower	77.5	HPFI	TC	X[1]	TBD

Note:

1 If CR > 8.5:1 Then pilot injection
If CR < 8.5:1 Then PCC's

TC = Turbocharger

Industry Involvement

- Dresser-Rand support – TLA engine donation, engineering drawings, and commitment for some conversion parts
- Altronic, Enginuity, and Hoerbiger commitment for hardware support/donations
- Industry personnel assistance – interviews, documentation, etc.

Industry Experience (Summary)

- Large bore NG 2-stroke engines are believed to have large safety factors
- Field data demonstrates safe operation at greater than 100% load
- Many of the large bore NG 2-stroke engines capable of increased speeds and loads without structural modifications
- No increase in failures noted for these engines

Industry Experience (Interviews)

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Chevron-Texaco - Clark RA Series

- Power Cylinder Porting Change
- New Heads & Pistons
- Scavenging Air Elbow
- No Turbo Upgrade
- 110% of Rated Load
- Ran Better, No Increased Failure Rates

Industry Experience (Interviews)

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SoCal Gas – Clark TLA-6 (7)

- Installed ABB Marine Turbocharger (19” Hg Boost)
- Intercooler w/ Wet Cooling Tower – Intake Air Temp. of 97°F
- Peak Pressure Balance w/ Std. Dev. < 30 psi.
- 115% of Rated Load Since 1958 w/ No Increase in Failure Rates or Maintenance

Industry Experience (Interviews)

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Williams Pipeline – Clark TLA-6 (12)

- Std. Turbocharger
- Intercooler Upgrade w/ Cooling Towers
- 105% of Rated Load for 20 yrs w/ No Increase in Failure Rates

Industry Experience

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Terry Smith – Industry Field Repair Expert

- Reviewed TLA-6 crankcase and upper block solid models
- Provided feedback on common TLA-6 failure modes and locations
- Will provide similar input for GMV and HBA engines

OEM Communications

- Memo from <u>Clark to Texaco</u> (1959) communicated results from a vibration analysis for an RA-6.
- Results indicated a resonant frequency exists at 340-350 RPM with a 7° amplitude.
- Clark recommended a max. speed of 320 RPM or flywheel modifications.

OEM Communications

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- Report from <u>Cooper-Bessemer to Texaco</u> (1989) regarding increasing speeds of GMV-6 (3) and GMVL-6 (1).
- Increased speed from 300 – 330 RPM.
- Balance study indicated that one of the GMV-6 engines needed to have additional reciprocating weight added.

GTI Project Conclusions (1/2)

- Increasing torque, not speed, can avoid approaching critical speeds.
- Industry data supports the conclusion that the engines have a large factor of safety, which will allow for the safe operation at the increased loads.
- Improved air delivery has long been demonstrated to reduce fuel consumption and emissions through leaner operation.

GTI Project Conclusions (2/2)

- Enhanced mixing can help reduce emissions, increase combustion stability, extend the lean limit, and decrease fuel consumption.
- Improved ignition techniques can reduce emissions, improve combustion stability, extend the lean limit, and decrease fuel consumption.
- HPFI, micro pilot ignition, and increased boost are proven technologies and are planned for implementation in Year 1 of the DOE program.
- Exhaust tuning benefits are engine specific and would have to be analyzed for each case.

Year 1 Project Schedule

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Task	O 04	N 04	D 04	J O5	F O5	M 05	A 05	M 05	J 05	J 05	A 05	S 05	O 05
1.1 Research Management Plan	🟦		complete										
1.2 Technology Assessment		🟦	🟦		complete								
1.3 Optical Engine Evaluations			🟦	🟦									
1.4 Component Procure & Fab			🟦	🟦	🟦	🟦							
1.5 System Test Plan						🟦	🟦 M1						
1.6 Uprate Systems Installation						🟦	🟦	🟦					
1.7 Testing of Uprate Systems									🟦	🟦	🟦 M2		
1.8 Annual Contractor Review												🟦	
Semi-Annual Progress Report							🟦						🟦

Outline

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Task 1.2: Technology Assessment Summary Table

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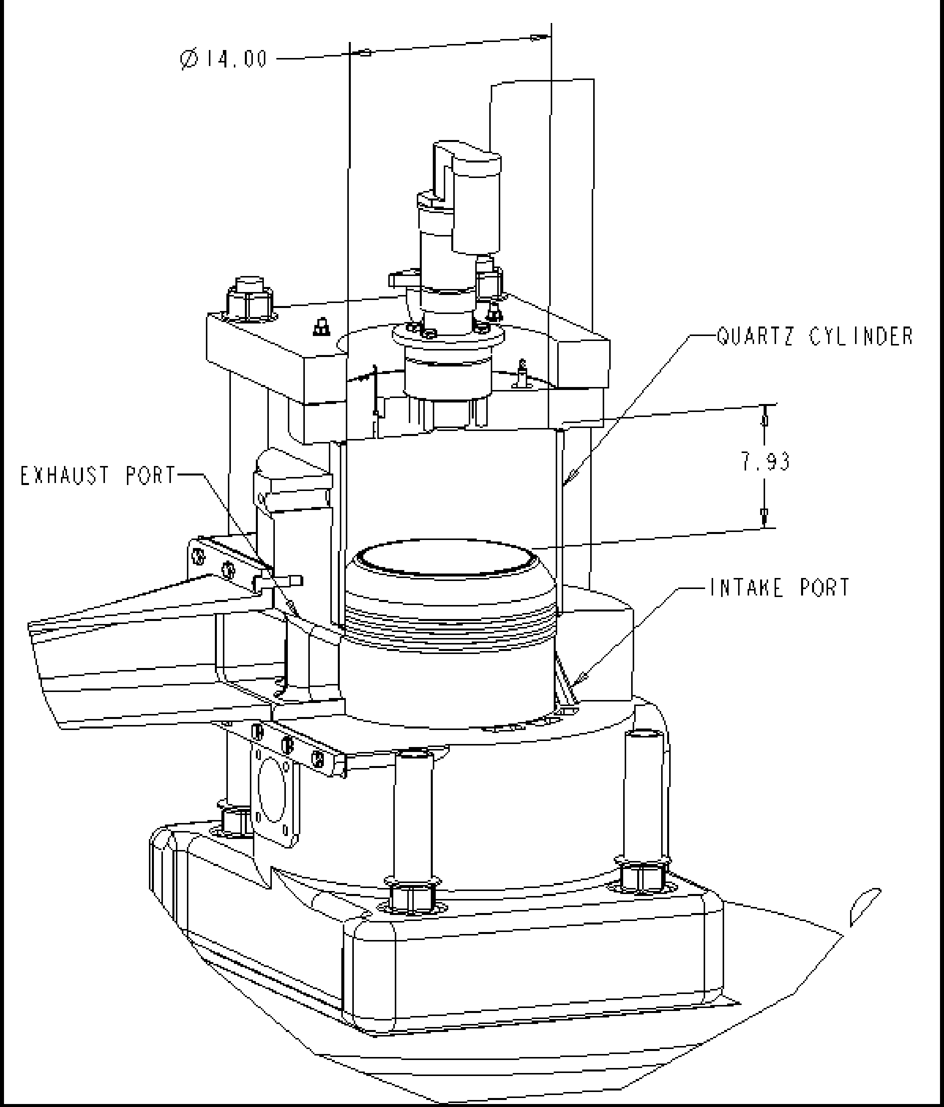
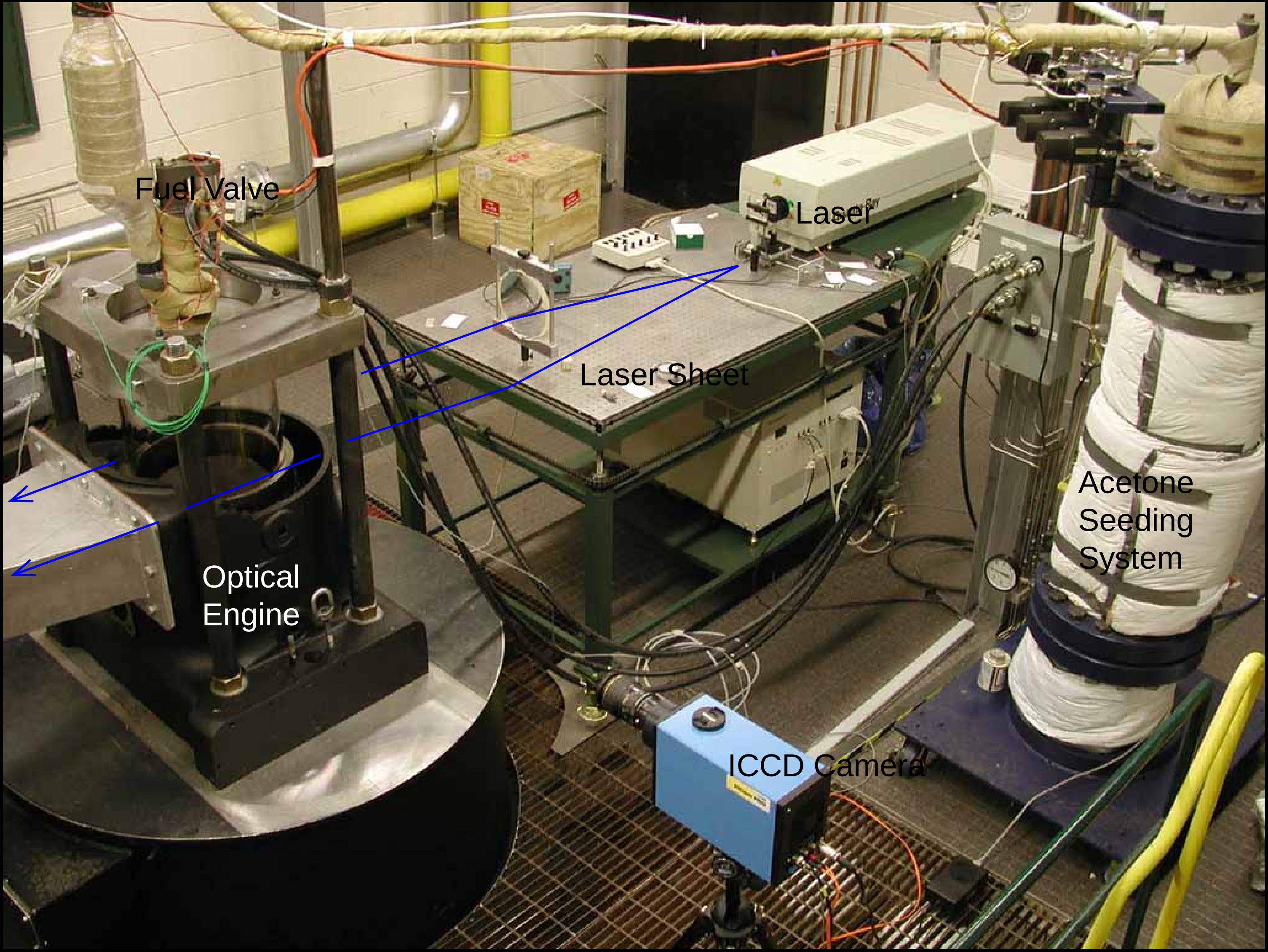
	ENGINE MODEL					
	(Percent of Overall Fleet)					
	BA, HBA HLA	TLA	KVG	KVS	GMV, GMVA	GMW, GMWA
	(7.5)	(7.1)	(3.1)	(4.4)	(5.1)	(9.3)
UPRATE TECHNOLOGY	**✓ Indicates Uprate Technology is applicable to engine model (subject to change per study)**					
Turbo Installation/ Upgrade •Pro: can help reduce emissions, increase engine output and extend the lean limit. •Con: may not be economical for units <1,500 HP	✓	✓	✓	✓	✓	✓
High Pressure Fuel Injection •Pro: Can extend the lean limit, increase combustion stability, and reduce emissions. Commercially available. •Con: may require turbo to gain full benefits	✓	✓	✓	✓	✓	✓
Pre-Combustion Chamber •Pro: Commercially available, extends the lean limit and increase combustion stability. •Con: may require turbo to gain full benefits	✓	✓	✓	✓	✓	✓
Pilot Fuel Ignition •Pro: Eliminates spark plugs, increases combustion stability, and reduction of emissions. Applicable to low-BMEP, non-turbocharged engines. •Con. Require second fuel source. Commercialization efforts needed.	✓	✓	✓	✓	✓	✓

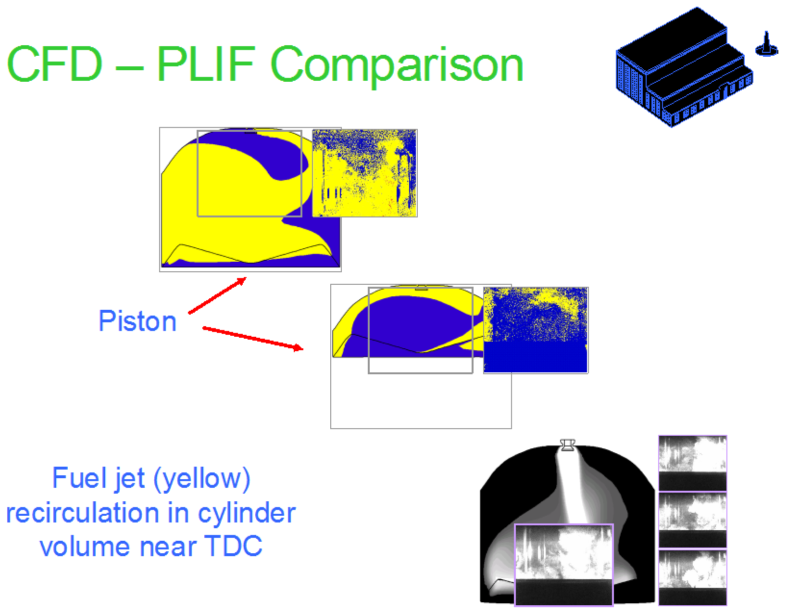
Task 1.3: Optical Engine (1/15): Description



Task 1.3: Optical Engine (2/15): PLIF Imaging Setup

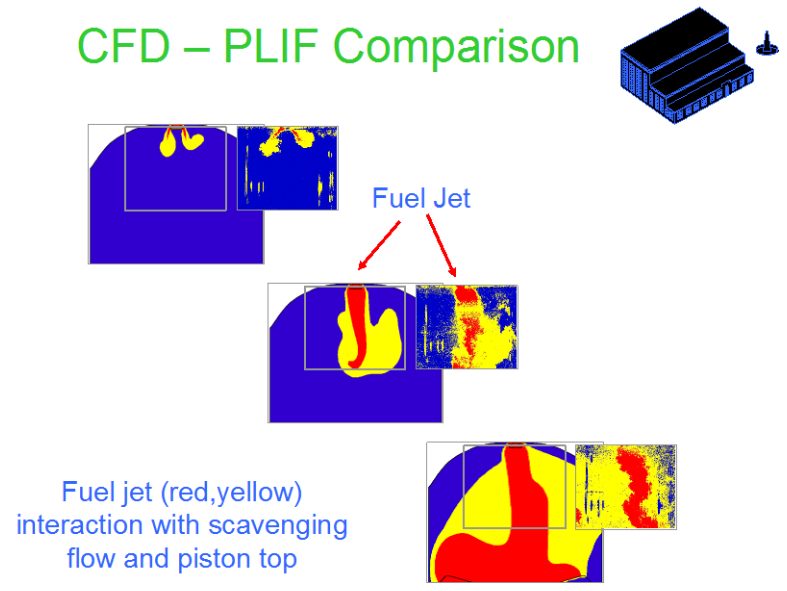


Task 1.3: Optical Engine (3/15): CFD Validation



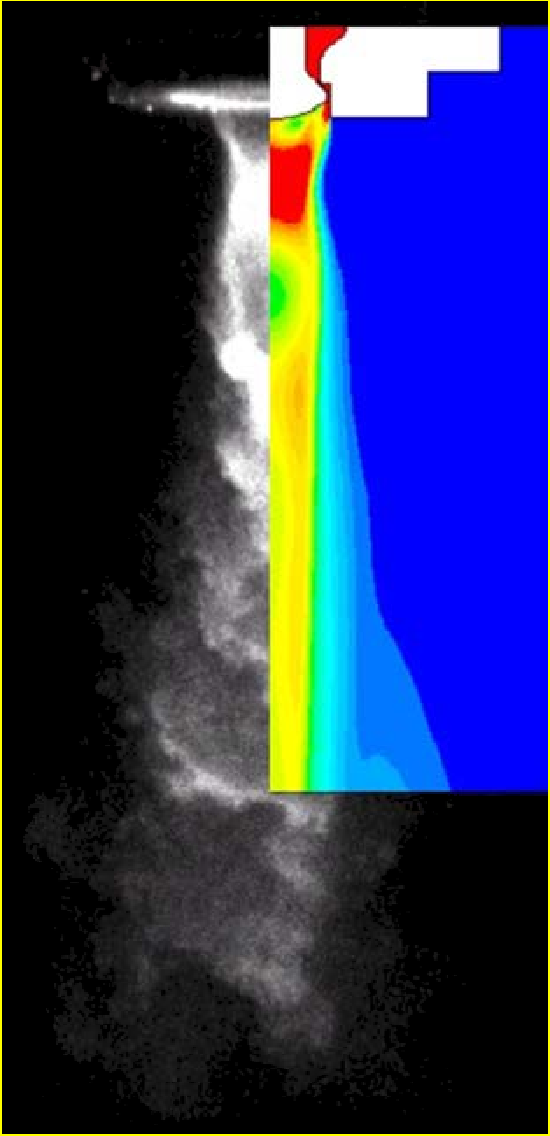
CFD – PLIF Comparison

Fuel jet (yellow) recirculation in cylinder volume near TDC



CFD – PLIF Comparison

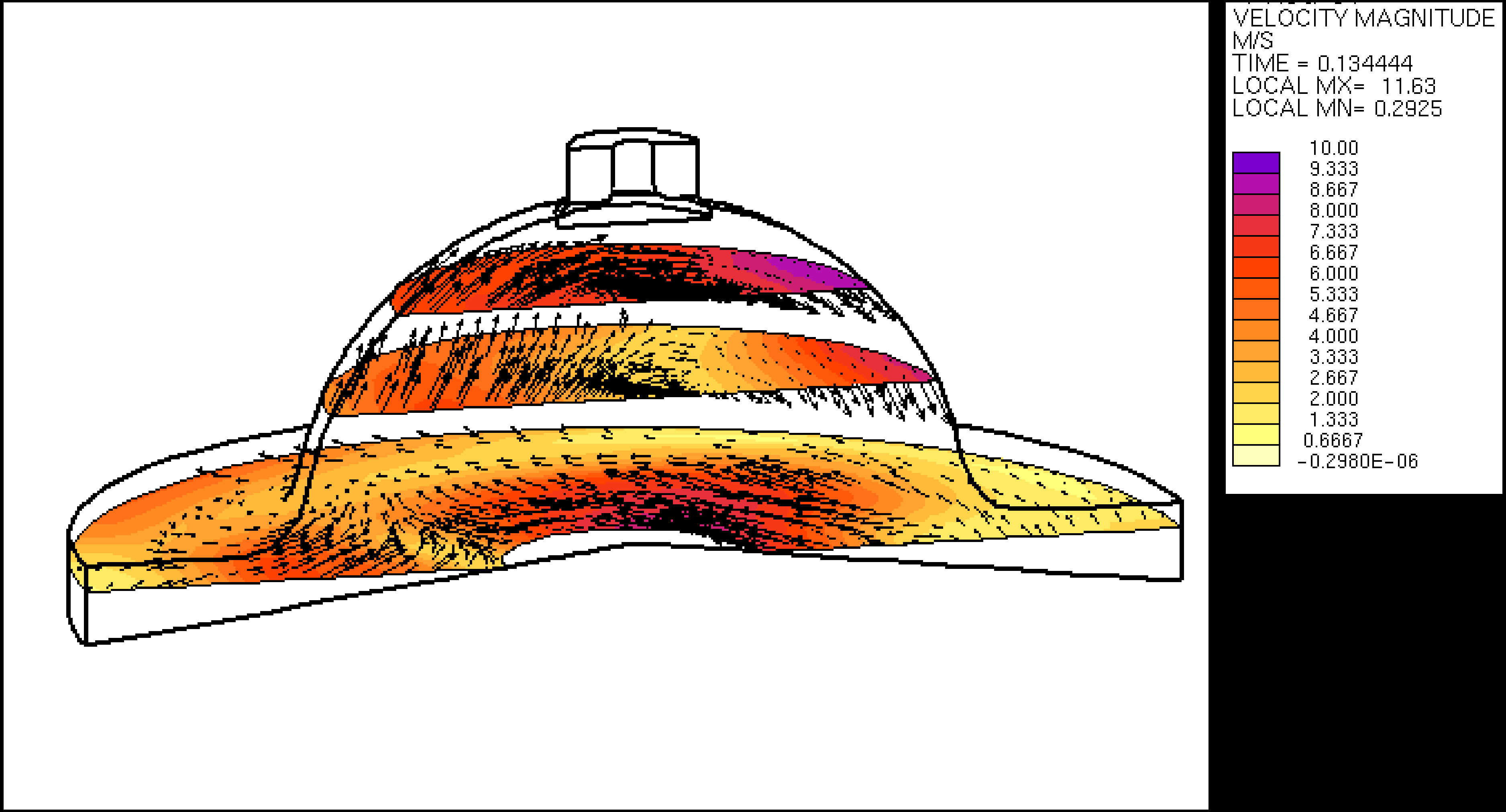
Fuel jet (red,yellow) interaction with scavenging flow and piston top



Task 1.3: Optical Engine (4/15): Clark TLA CFD Analysis

- Optical engine has 14” bore; TLA has 17” bore
- Not practical to modify for larger bore
- Performed mixing studies using CFD, previously validated with optical engine results
  - Case #1 - OEM TLA with standard mixing model
  - Case #2 - TLA with enhanced mixing model and OEM piston
  - Case #3 - TLA with enhanced mixing model with modified crown piston

Task 1.3: Optical Engine (5/15): CFD Flow Field @ IGNITION



Task 1.3: Optical Engine (6/15): CFD Fuel Distribution @ IGNITION

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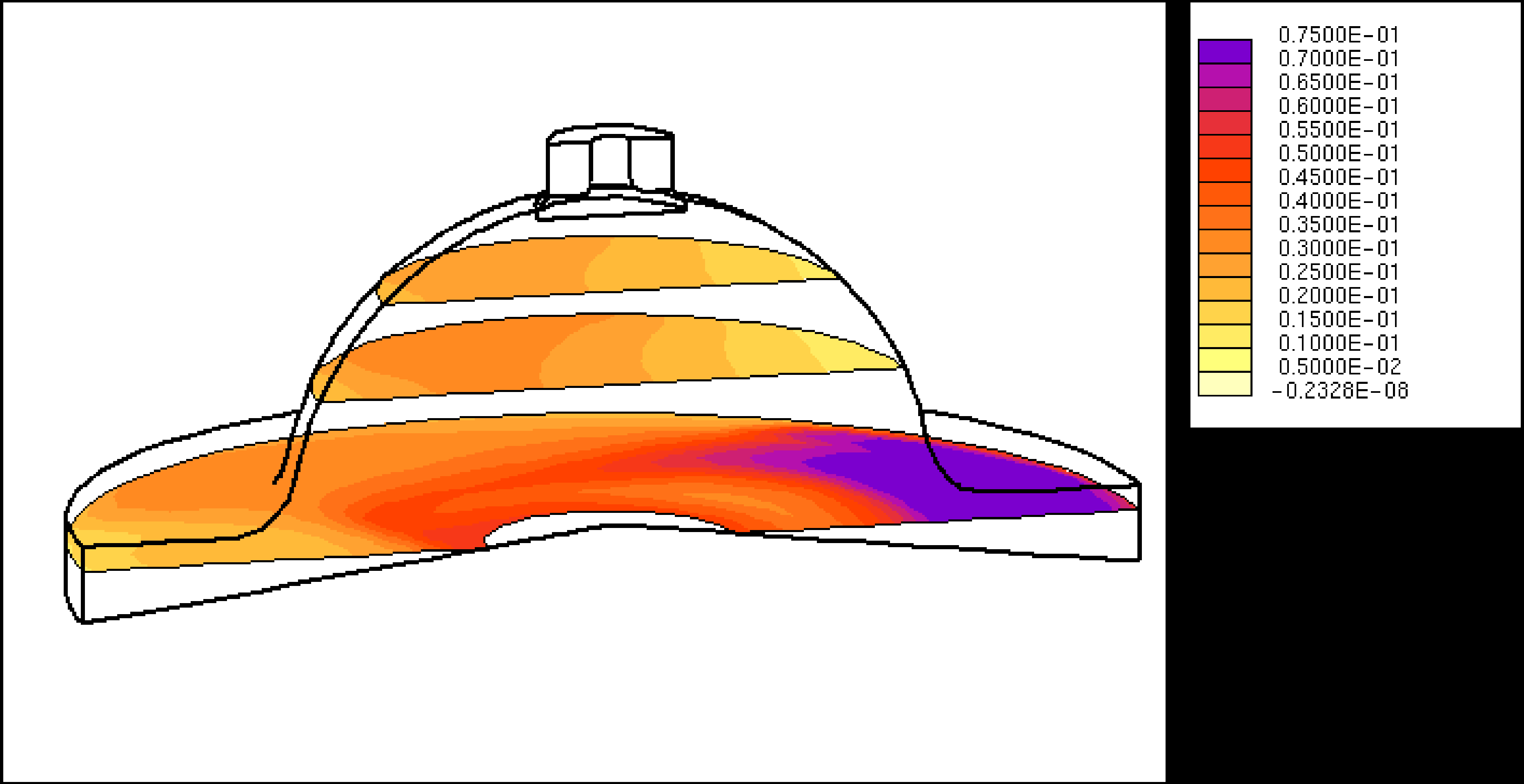
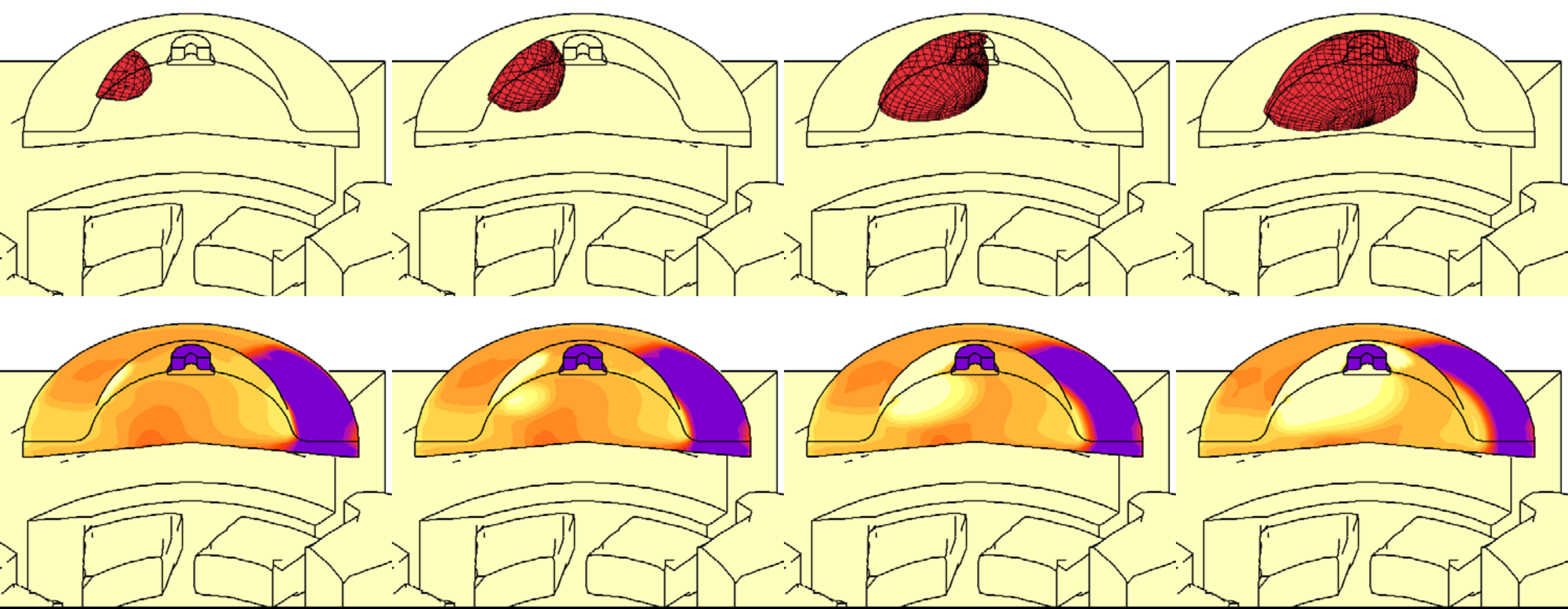
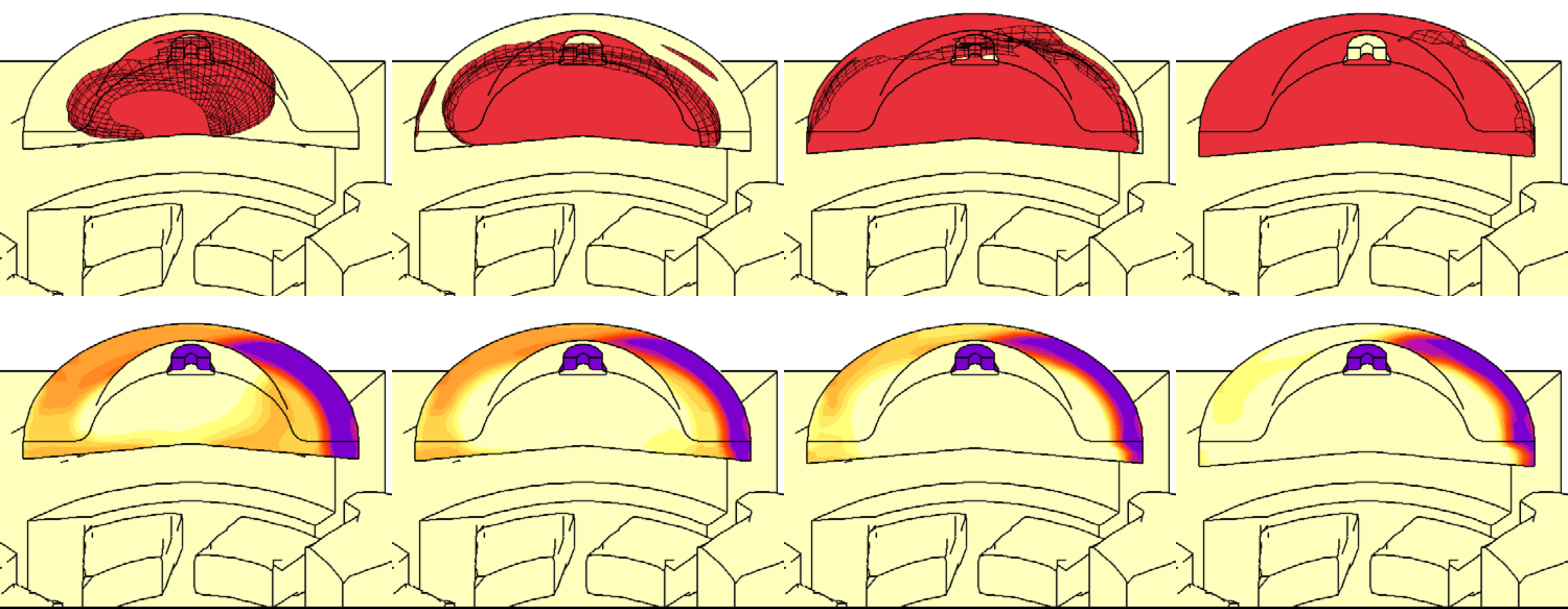


Task 1.3: Optical Engine (7/15): CFD Flame Propagation & Fuel Consumption

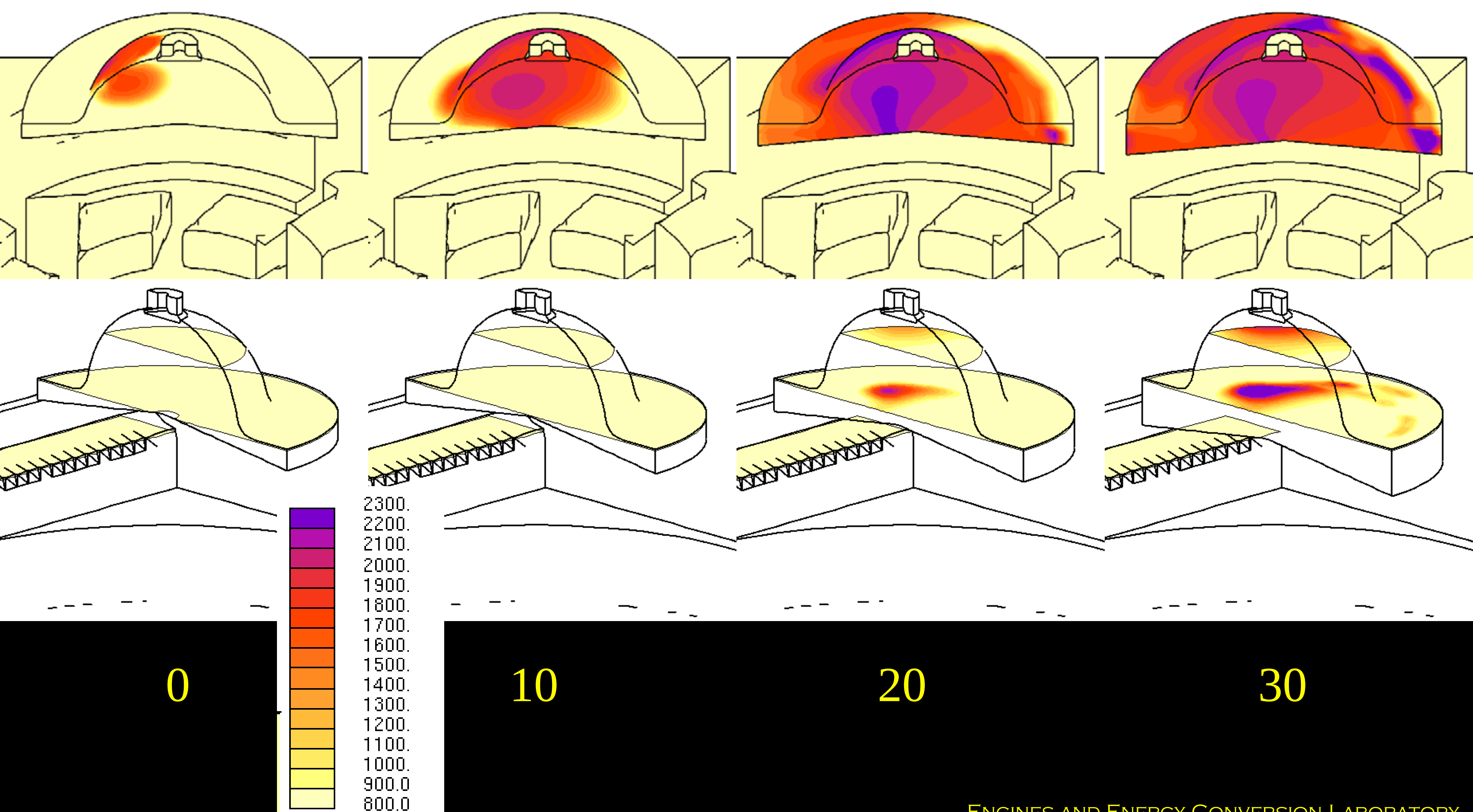


Task 1.3: Optical Engine (8/15): CFD Flame Propagation & Fuel Consumption

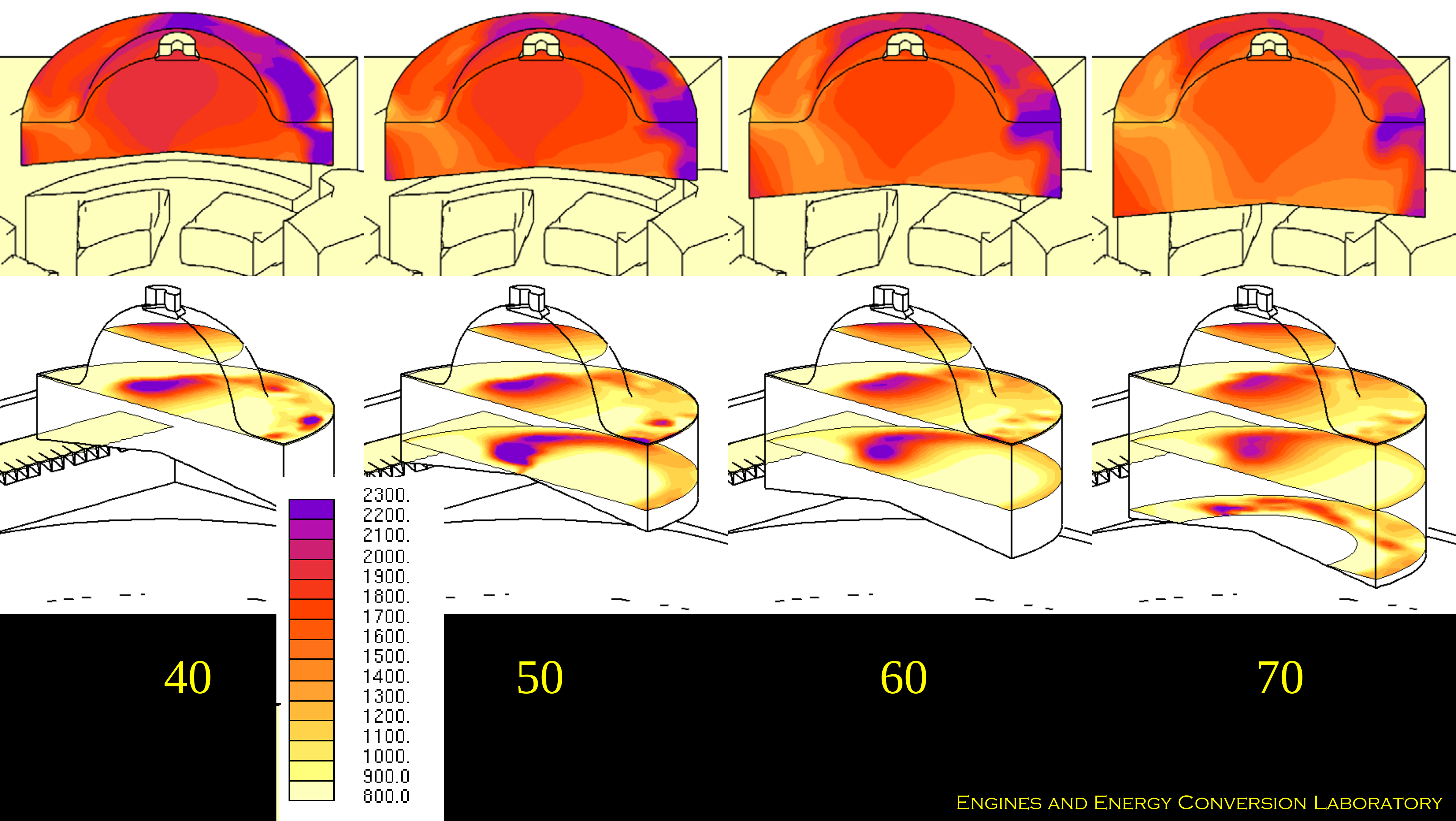


10 14 18 22

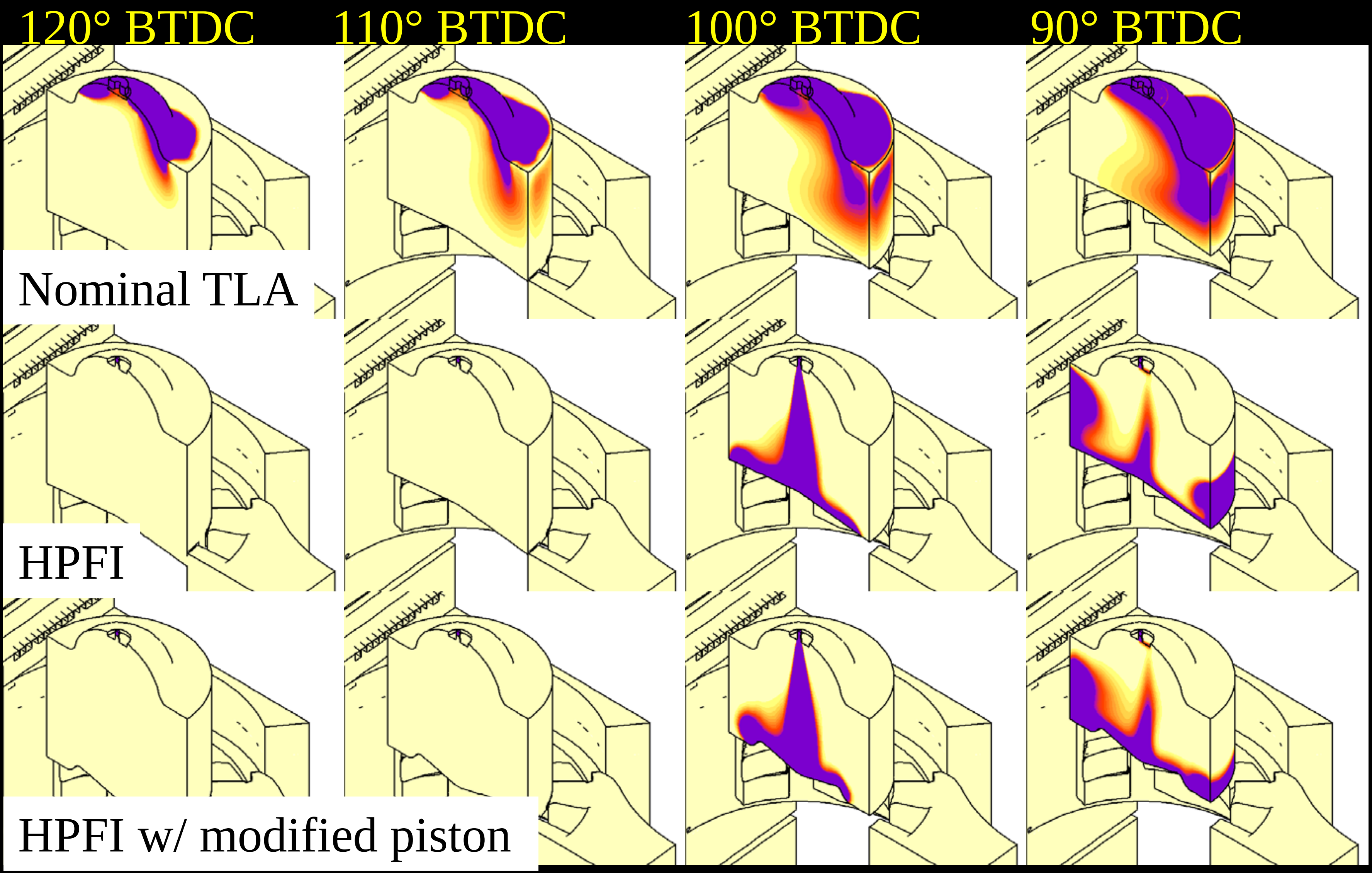
Task 1.3: Optical Engine (9/15): CFD Temperature & NO



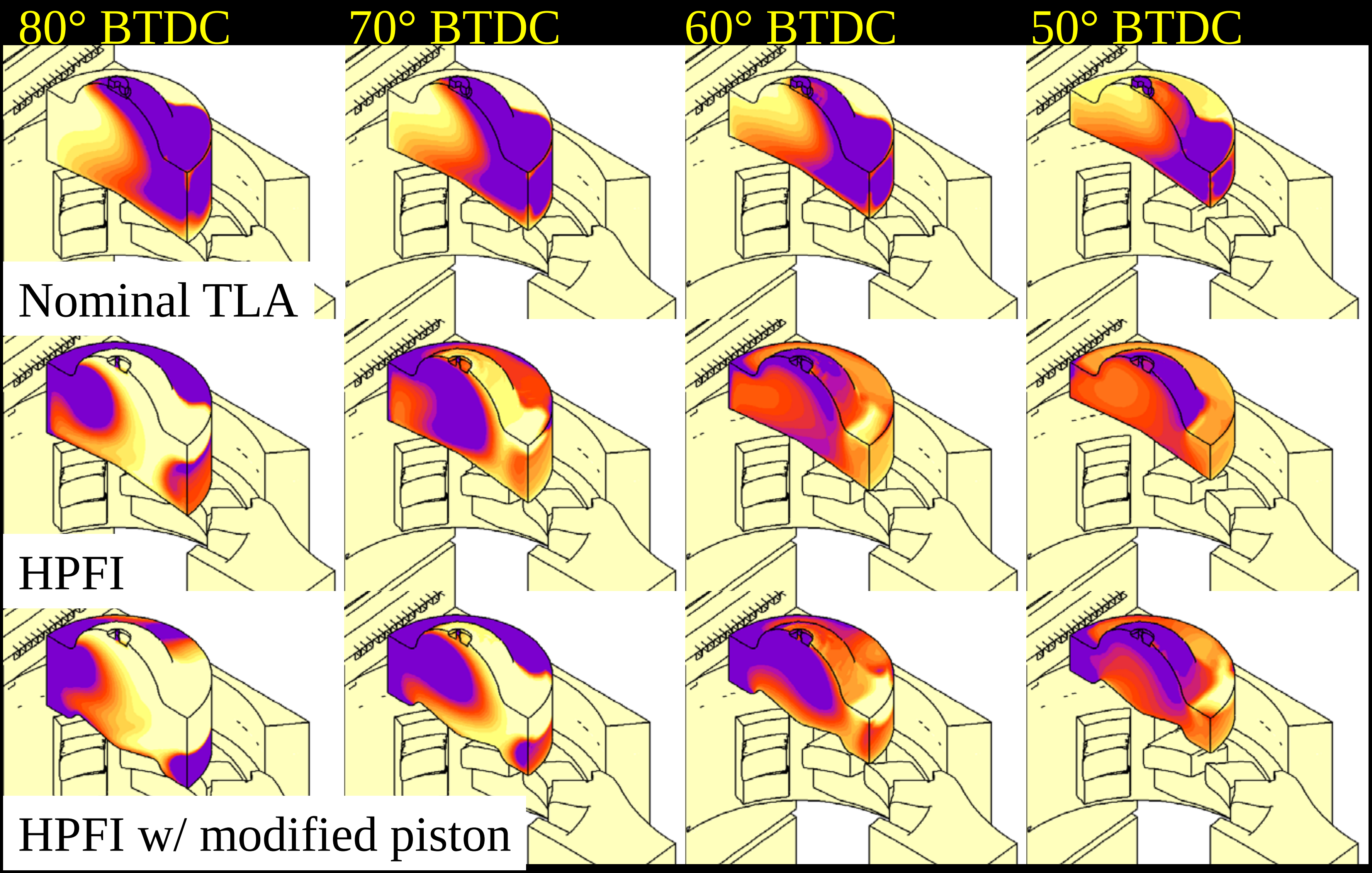
Task 1.3: Optical Engine (10/15): CFD Temperature & NO



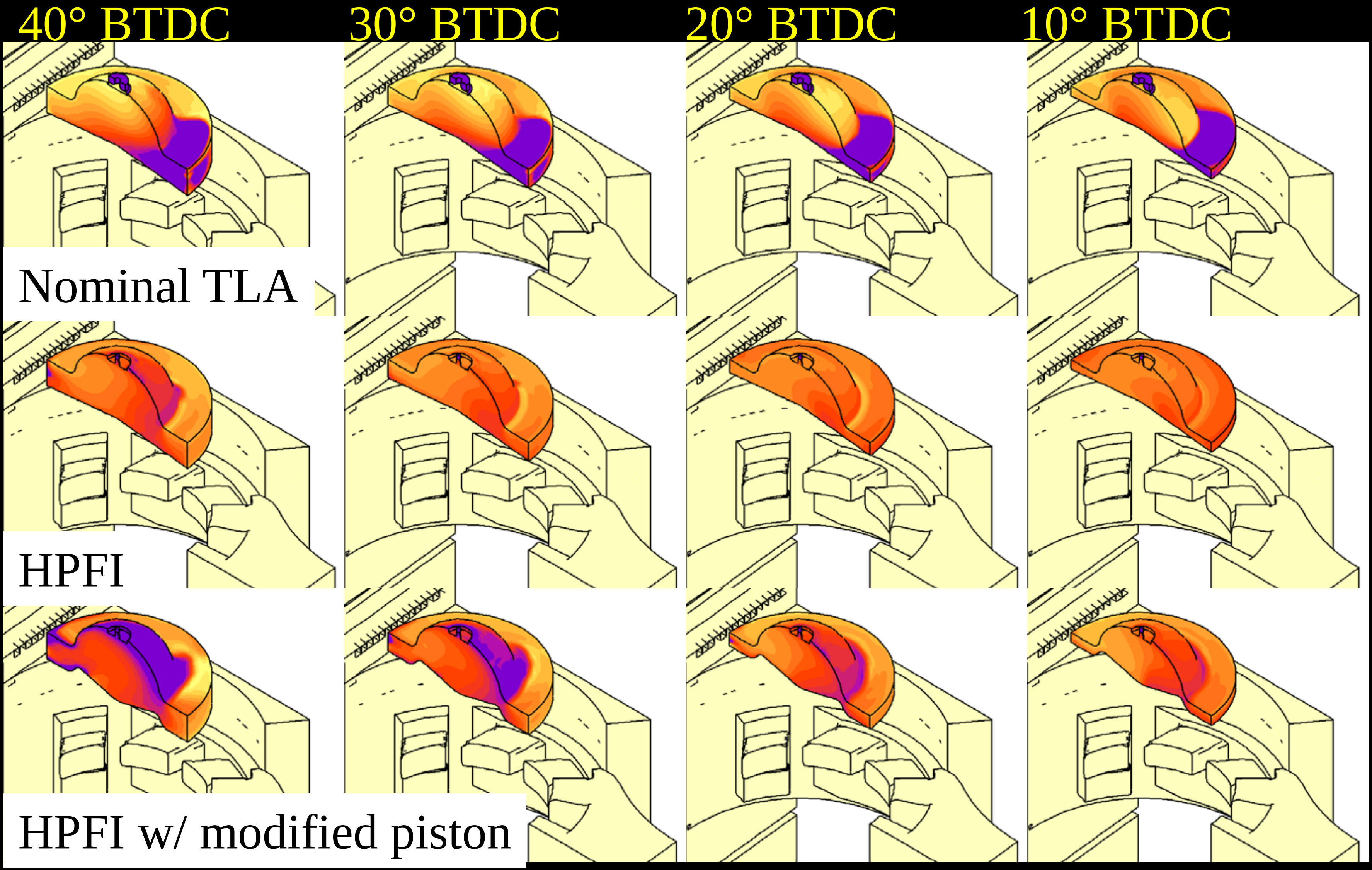
Task 1.3: Optical Engine (11/15): Mixing Comparison



Task 1.3: Optical Engine (12/15): Mixing Comparison



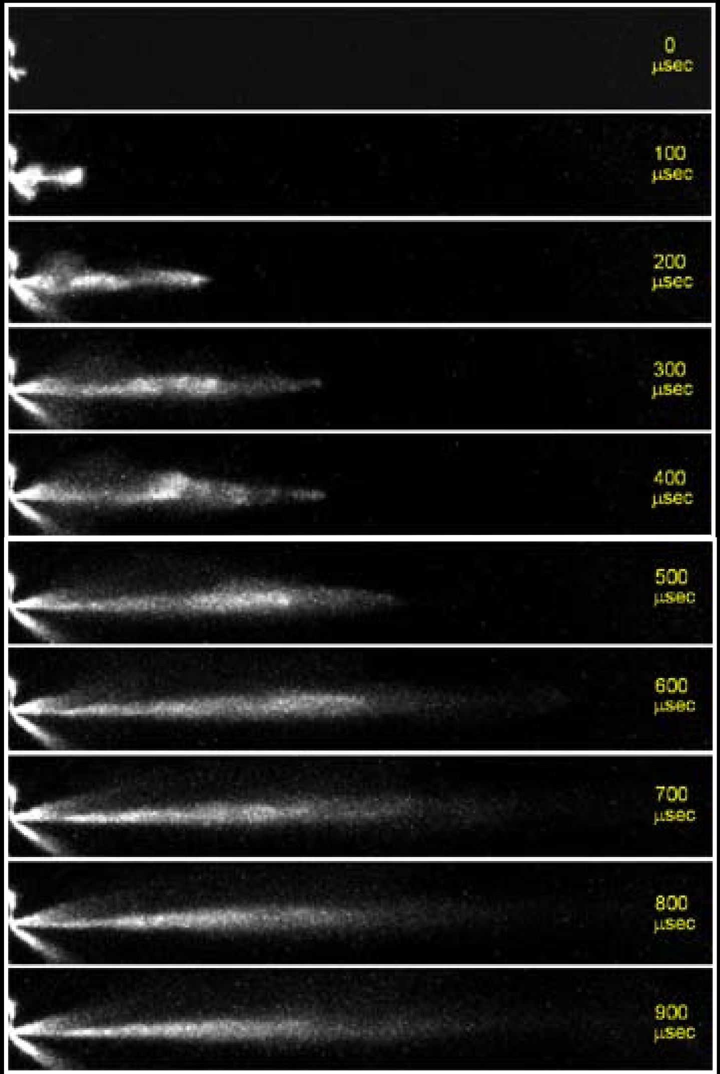
Task 1.3: Optical Engine (13/15): Mixing Comparison

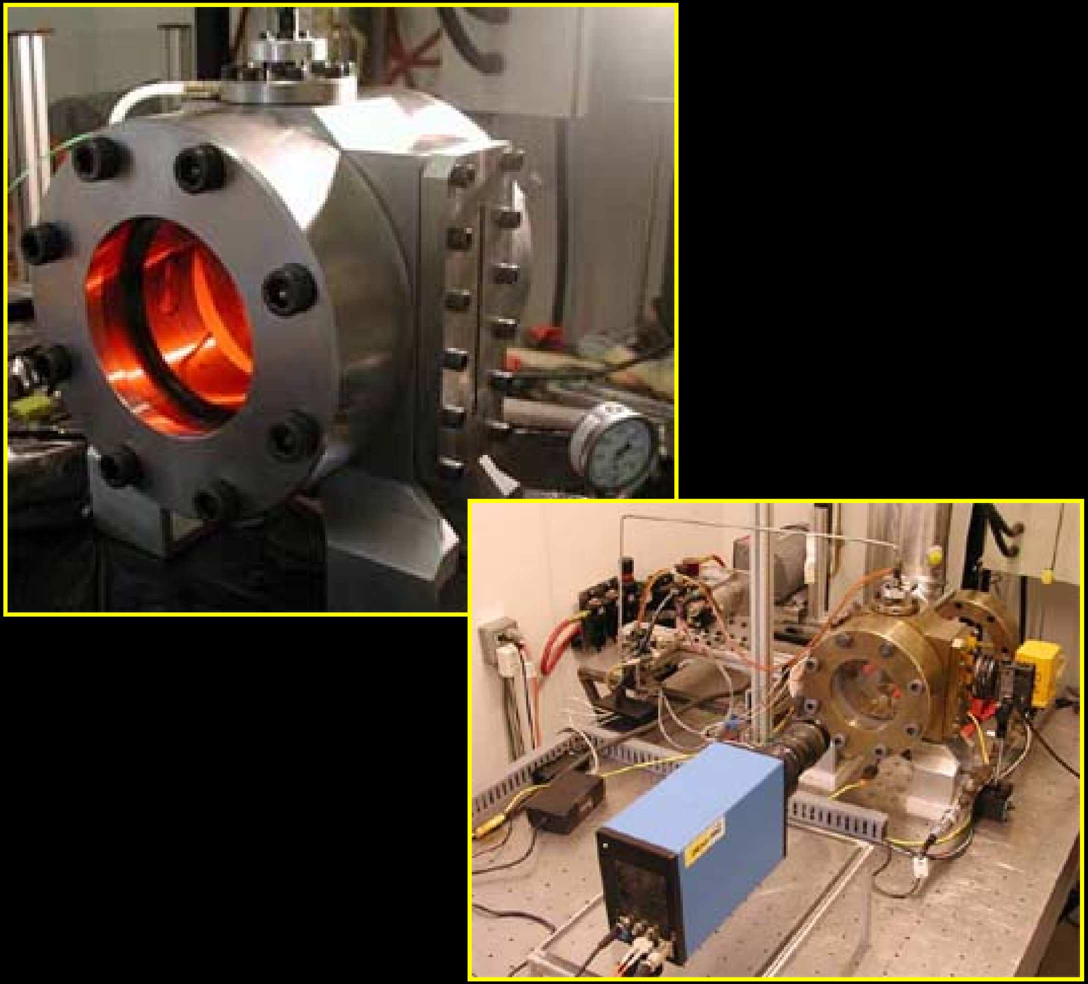


Task 1.3: Optical Engine (14/15)

- CFD work provides required information on mixing
- To examine micropilot ignition, utilize combustion test chamber (CTC)
- CTC will allow imaging of pilot injection with new injectors prior to engine testing

Task 1.3: Optical Engine (15/15): Combustion Test Chamber





Task 1.4: Component Procurement & Fabrication (1/15)

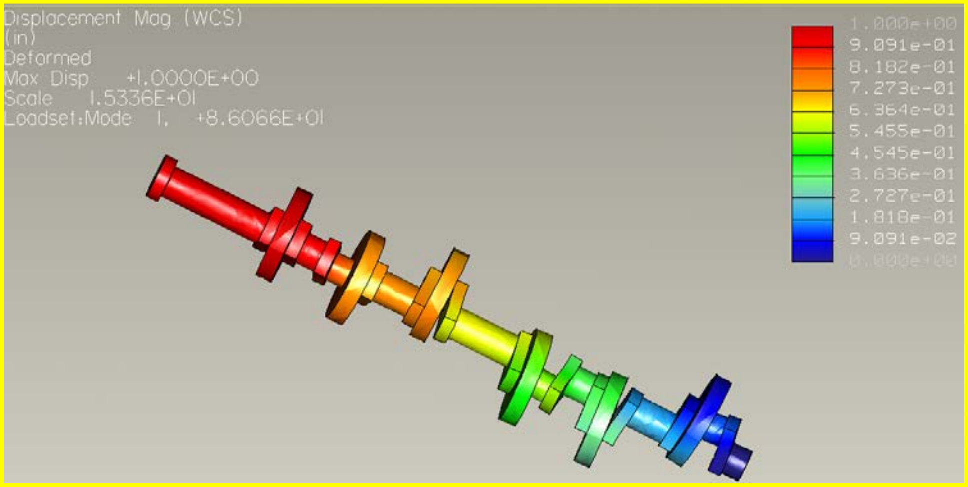
- Request for OEM components has been submitted to Dresser-Rand
- Hoerbiger and Enginuity have offered to provide high pressure fuel injection systems
- Enginuity is donating an Impact cylinder pressure monitoring system
- Altronic is donating CPU 2000 spark ignition system with add-on module for micropilot injection control

Task 1.4: Component Procurement & Fabrication (2/15): Modal and Dynamic Stress Analysis

- Modal analysis (Pro Mechanica) performed to assess possibility of utilizing speed increases
- Stress analysis performed to examine effects of increasing torque
- Dynamic forces accounted for by utilizing Working Model and simulation feature in Pro Mechanica
- High stress locations identified using Finite Element Analysis

Task 1.4: Component Procurement & Fabrication (3/15): TLA Crankshaft Modal Analysis

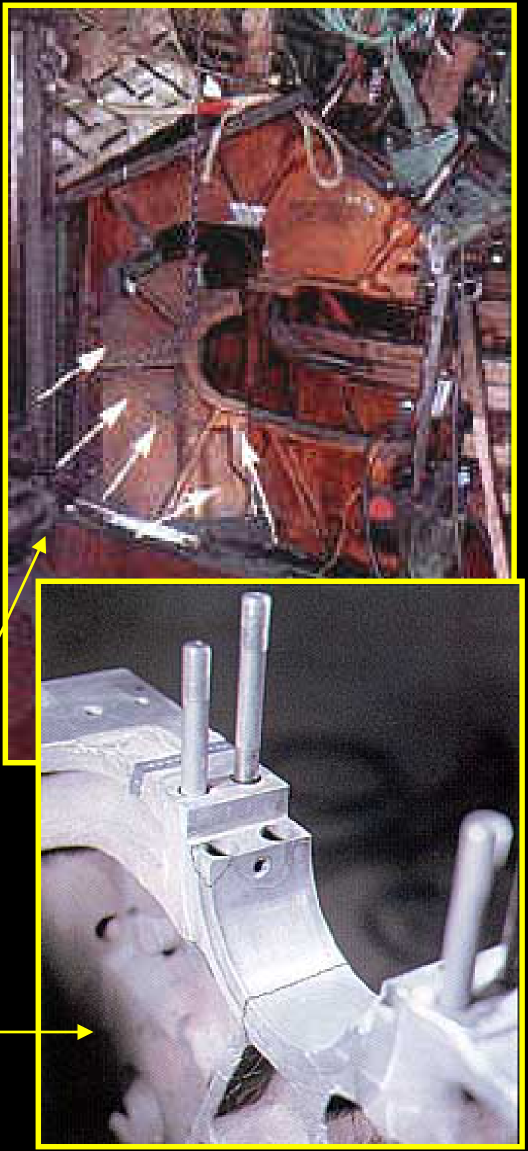
- Added ‘mass’ (lobes) to crankshaft to simulate piston/connecting rod weight.
- Constrained bearing at non-flywheel end to 1 rotational DOF, all other bearing supports to 1 rotational and 1 translational DOF.



- Modal Analysis results indicate the first resonant frequency occurs at 34Hz (2040RPM).
  - The 5th, 6th, and 7th order critical speeds are 408, 340, and 291 RPM, respectively.

Task 1.4: Component Procurement & Fabrication (4/15): TLA-6 Stress Analysis

- Given the forces of the power and compressor pistons, the frame stresses are examined.
- The frame stresses of standard TLA configuration are compared to the frame stresses of the uprated TLA configuration.

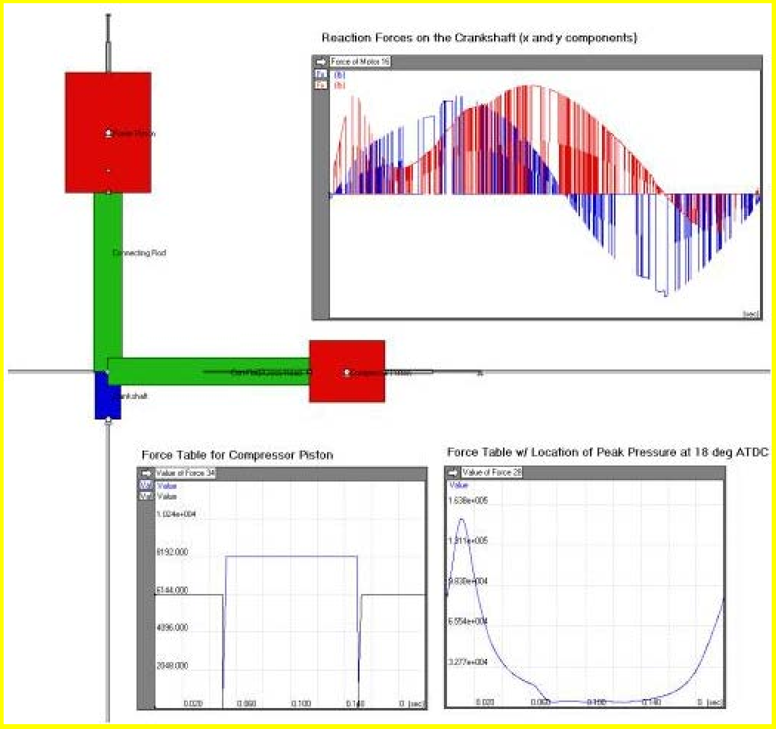


GMV crankcase

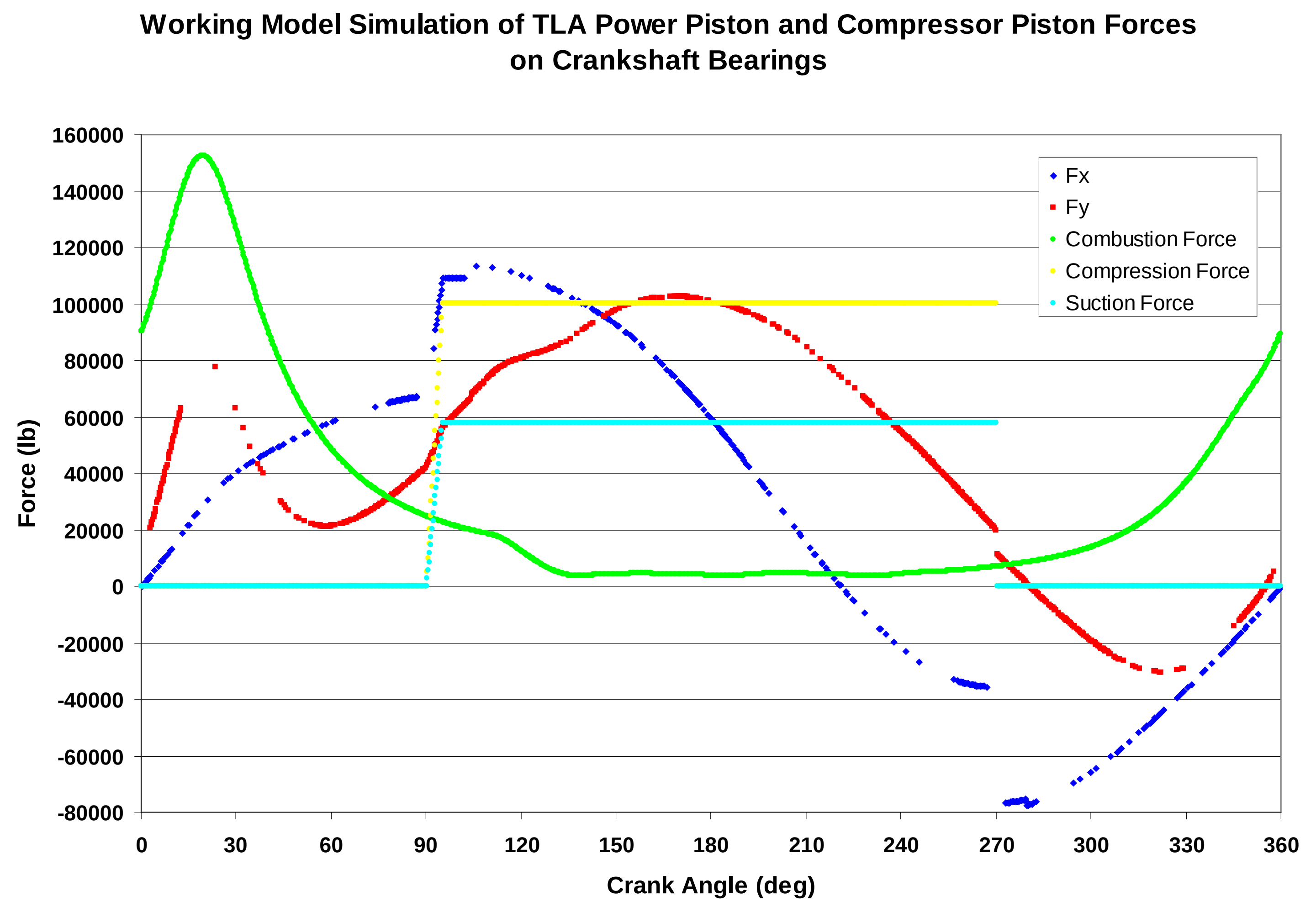
Superior crankcase
(Reynolds-French)

Task 1.4: Component Procurement & Fabrication (5/15): TLA-6 Dynamic Analysis

- Developed dynamic model using Working Model 2D software
- Determined dynamic forces on crankshaft bearings
- These forces used as the loading forces for the crankcase FEA modeling



Task 1.4: Component Procurement & Fabrication (6/15): TLA-6 Dynamic Analysis



Task 1.4: Component Procurement & Fabrication (7/15): TLA-6 Dynamic Stress Analysis

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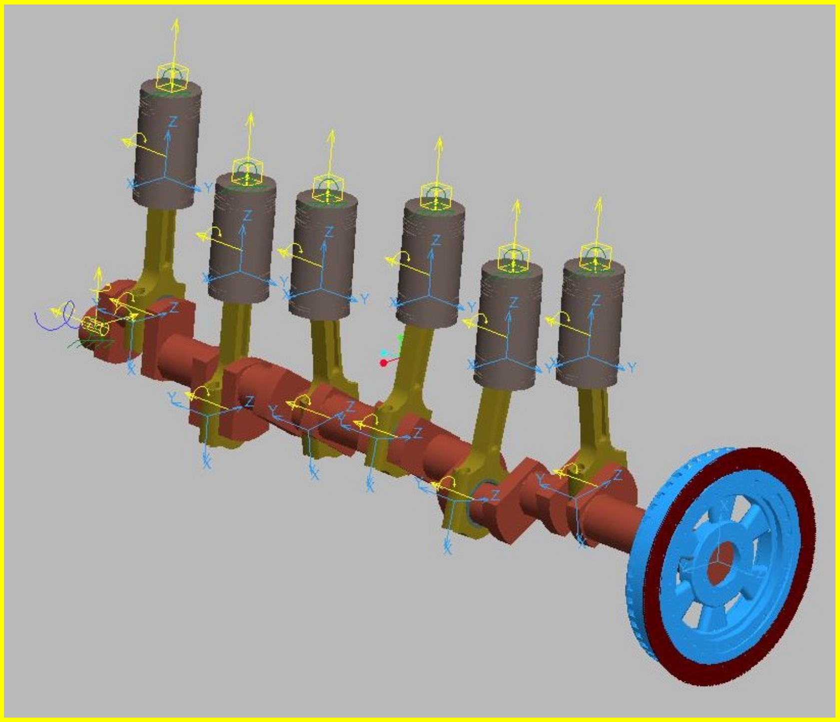
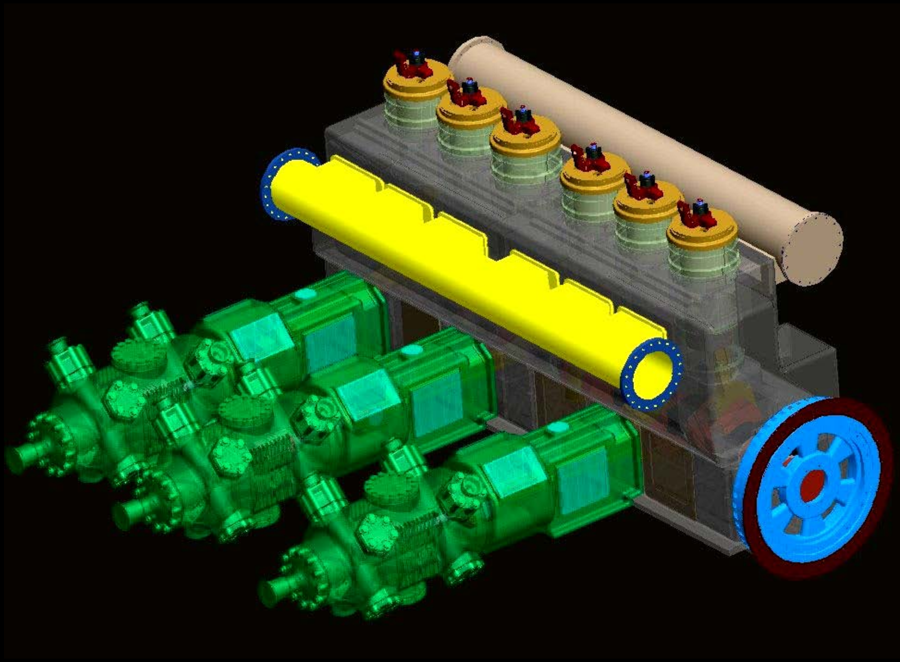
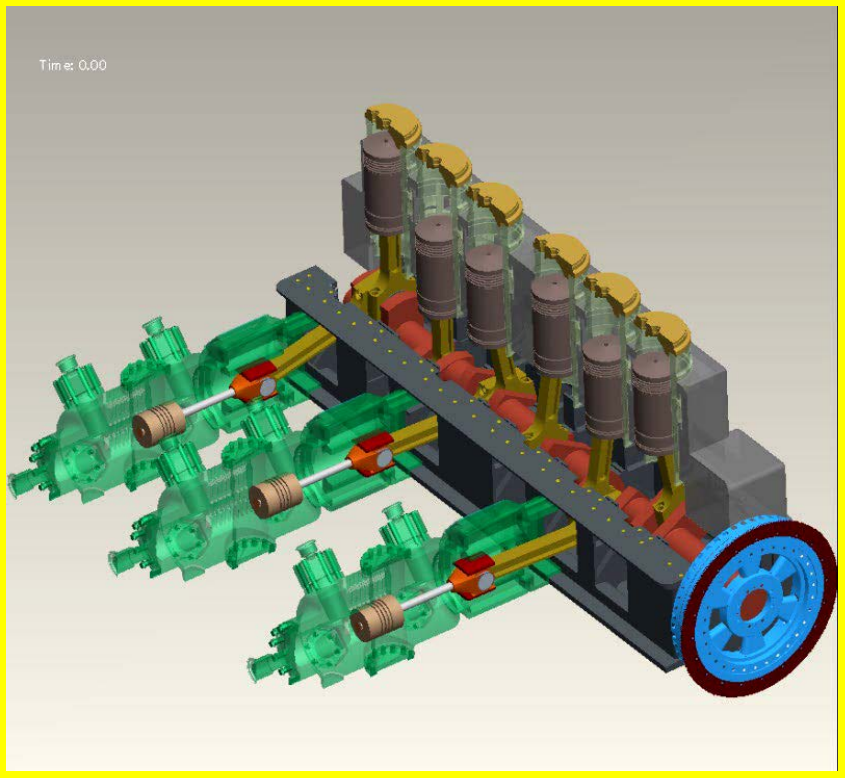
- Motion added to Pro/E solid model using Pro/Mechanica's Motion capability.





Task 1.4: Component Procurement & Fabrication (8/15): TLA-6 Dynamic Stress Analysis

- Pro/Mechanism are used to determine the dynamic forces on crankshaft bearings
- These forces are compared to the Working Model simulation results and incorporated into the FEA stress modeling



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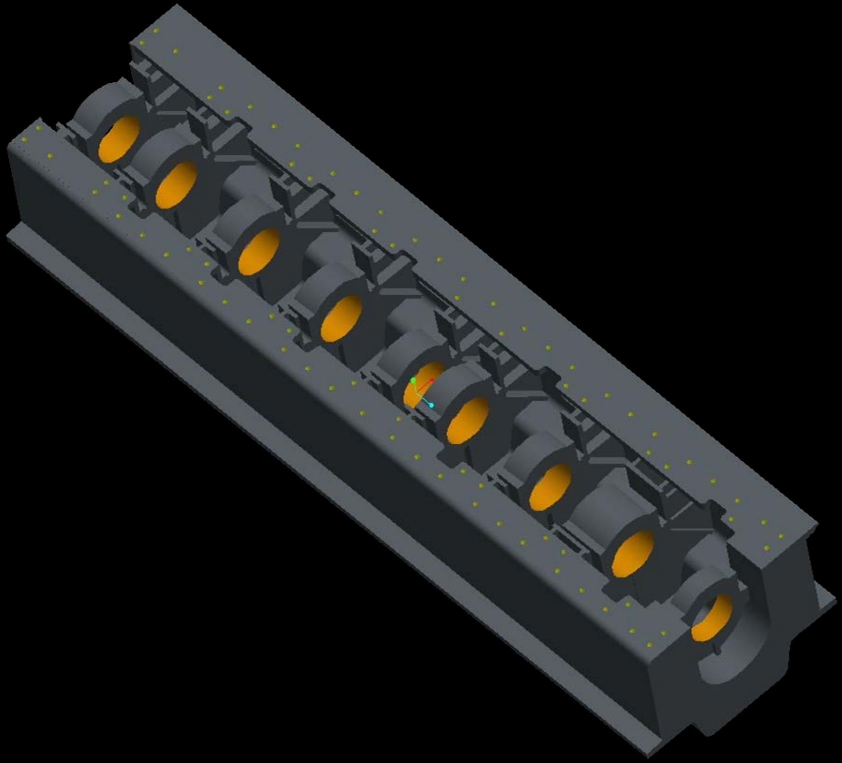
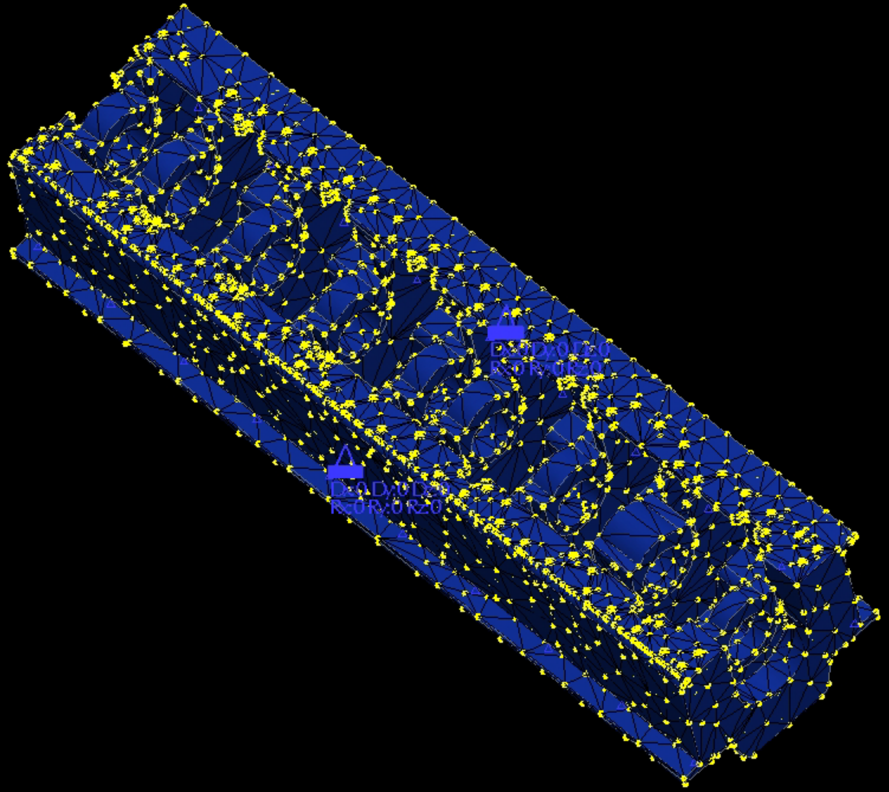
Task 1.4: Component Procurement & Fabrication (9/15): TLA-6 Static Stress Analysis

- TLA Crankcase with bearing surfaces and block stud locations highlighted

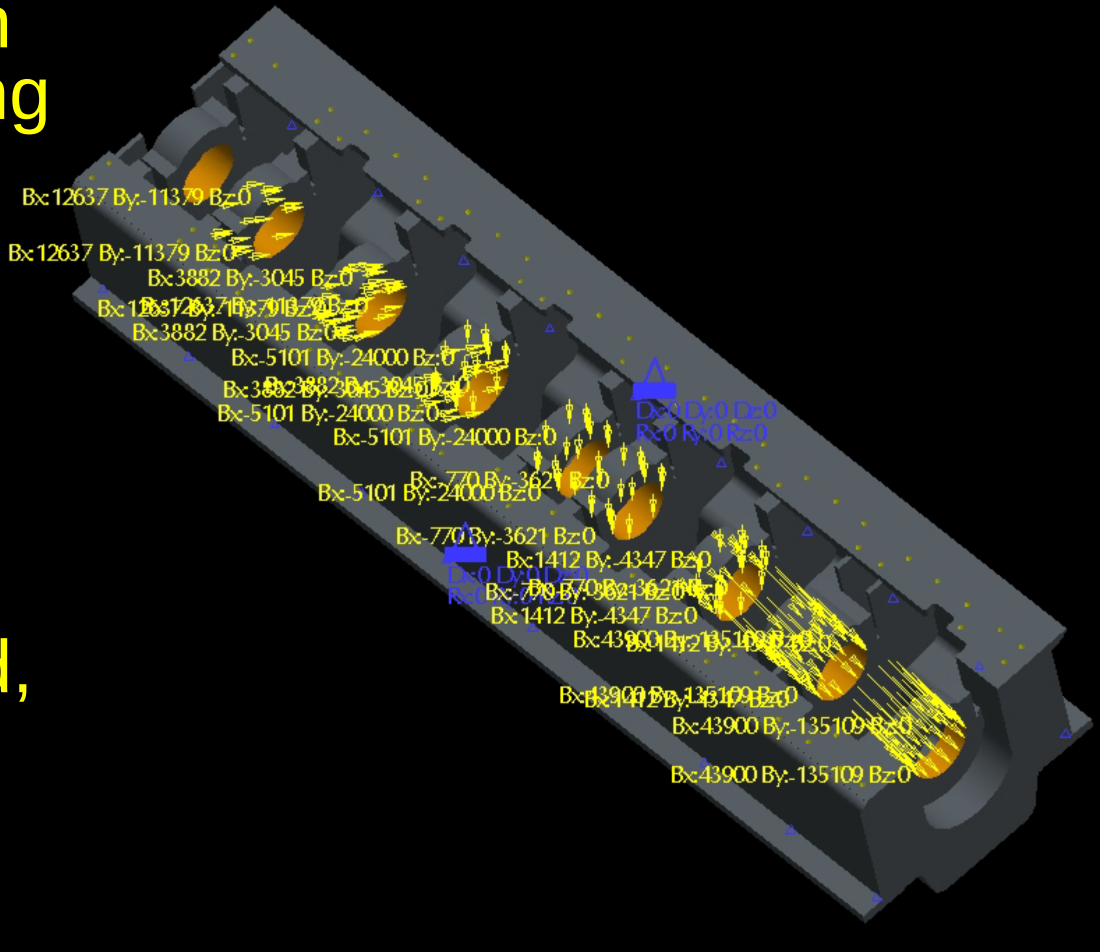
- Simplified TLA Crankcase
- Meshed for Finite Element Analysis (FEA)





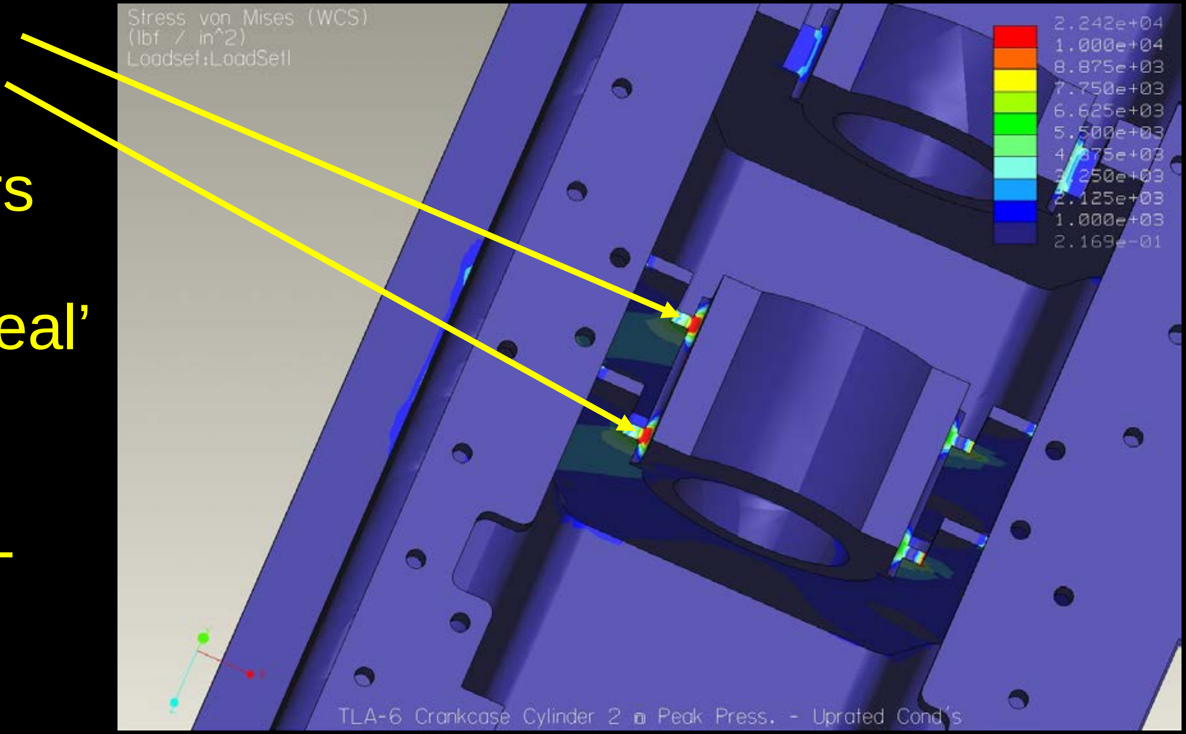
Task 1.4: Component Procurement & Fabrication (10/15): TLA-6 Static Stress Analysis

- TLA Crankcase with initial bearing loading conditions (from dynamic modeling)
- Loading conditions are based upon single cylinder at peak pressure (18° ATDC)
- Six cases evaluated, one case for each power cylinder at peak pressure



Task 1.4: Component Procurement & Fabrication (11/15): TLA-6 Stress Analysis Results

- Most common locations of high stress
- Stress conc. factors could be artificially elevated due to ‘ideal’ nature of model
- Max. FEA stress results are ~22ksi - compression
- Class 30 gray cast iron has S_{uc}=109ksi

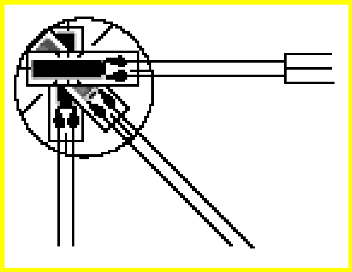


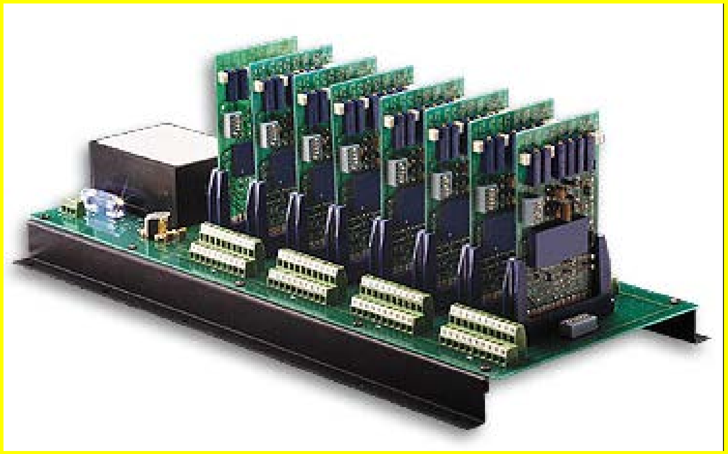
Task 1.4: Component Procurement & Fabrication (12/15): Frame Stress Model Verification

- Stress models are being duplicated for the EECL's Cooper-Bessemer GMV-4
- The results from the stress models are to be verified against measured frame stresses on the GMV-4
- Strain gages (donated by Kistler) will be attached to the crankcase
- High stress locations will be determined by analyzing the FEA modeling results

Task 1.4: Component Procurement & Fabrication (13/15): Frame Stress Model Verification

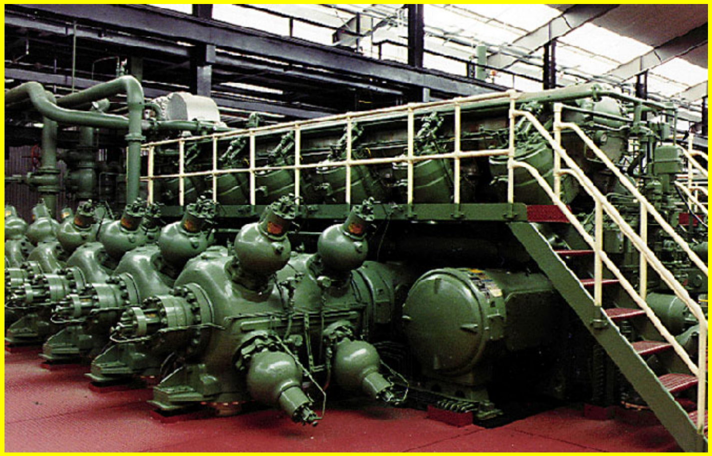
- Rosette strain gages will be used
- Purchased Omega strain gage signal conditioning system
- Will integrate with the EECL's existing networkable data acquisition hardware





Task 1.4: Component Procurement & Fabrication (14/15): Future Analysis Efforts

- The frame stress analysis process is to be applied to other candidate engines
- Analysis on other candidate engines planned:
  - Clark HBA Series
  - Cooper-Bessemer GMV Series



Task 1.4: Component Procurement & Fabrication (15/15): Preliminary Conclusions

- Uprating may be successfully accomplished by a combination of increased torque and speed
- Modal analysis results indicate critical operating speeds are above targeted operating speeds
- Modal analysis results fit within reasonable range of historical resonant speeds of other similar engines
- Frame stress analysis predictions indicate a 10% to 15% increase in frame stresses with a 20% increase in engine power
- Frame stress results indicate a negligible reduction in factor of safety (TLA-6)
- Frame stress modeling still needs to be validated

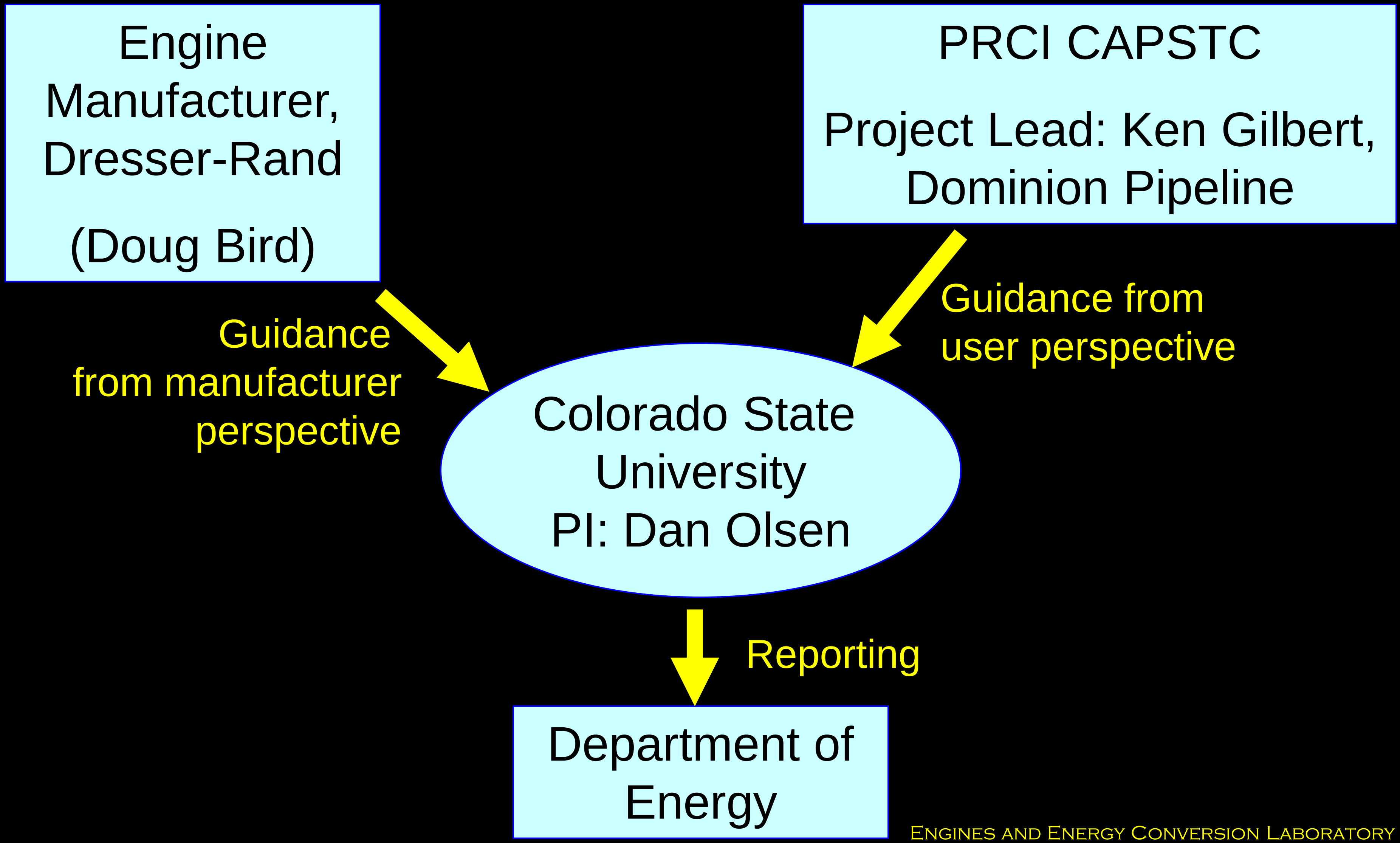
Task 1.5: System Test Plan

Configuration	**Operating Conditions**	**Measures**
Stock	Equivalence Ratio Map, Speed Map	Std. Temperatures, Pressures, Combustion Stats., HAPS, & Criteria Pollutants
Enhanced Mixing		
Enhanced Mixing and Ignition		
Optimal Control Methodology		
Uprated	Variation of Load & Speed (up to 20% BHP ↑)	

Outline

- Executive Summary
- Previous Work done with GTI Funds
- DOE Year 1 Results To-Date
- Planned Research Activities

Task 1.4: Component Procurement & Fabrication



Engine Manufacturer, Dresser-Rand

(Doug Bird)

PRCI CAPSTC

Project Lead: Ken Gilbert, Dominion Pipeline

Guidance from manufacturer perspective

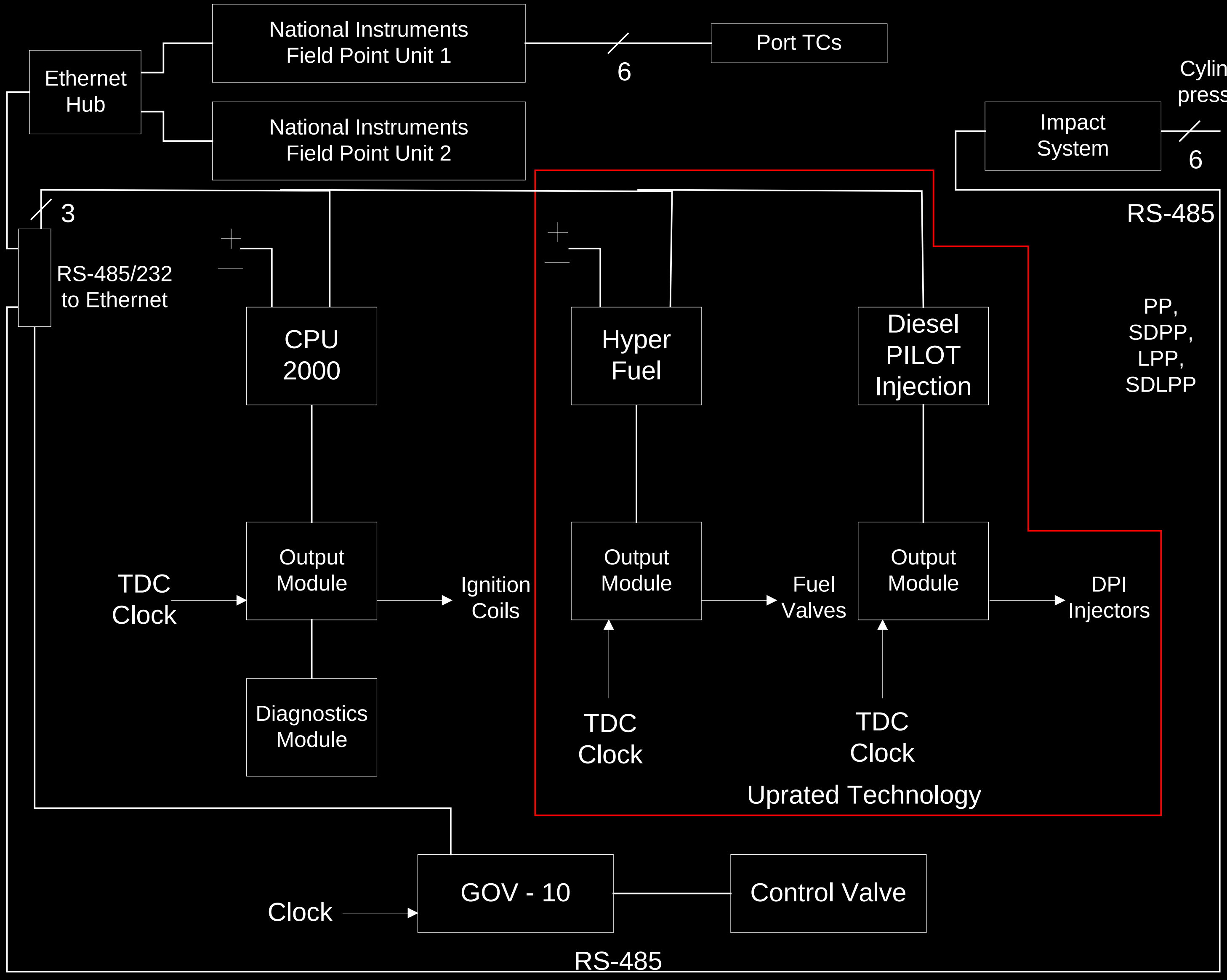
Guidance from user perspective

Colorado State University
PI: Dan Olsen

Reporting

Department of Energy

Task 1.4: Component Procurement & Fabrication: Advanced Controls

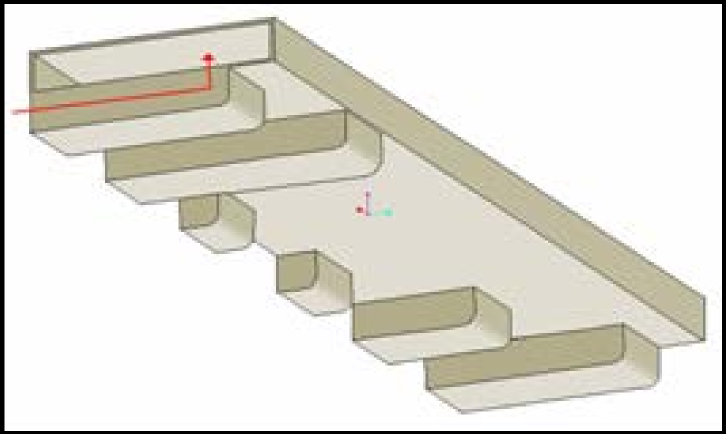


Task 1.4: Component Procurement & Fabrication:

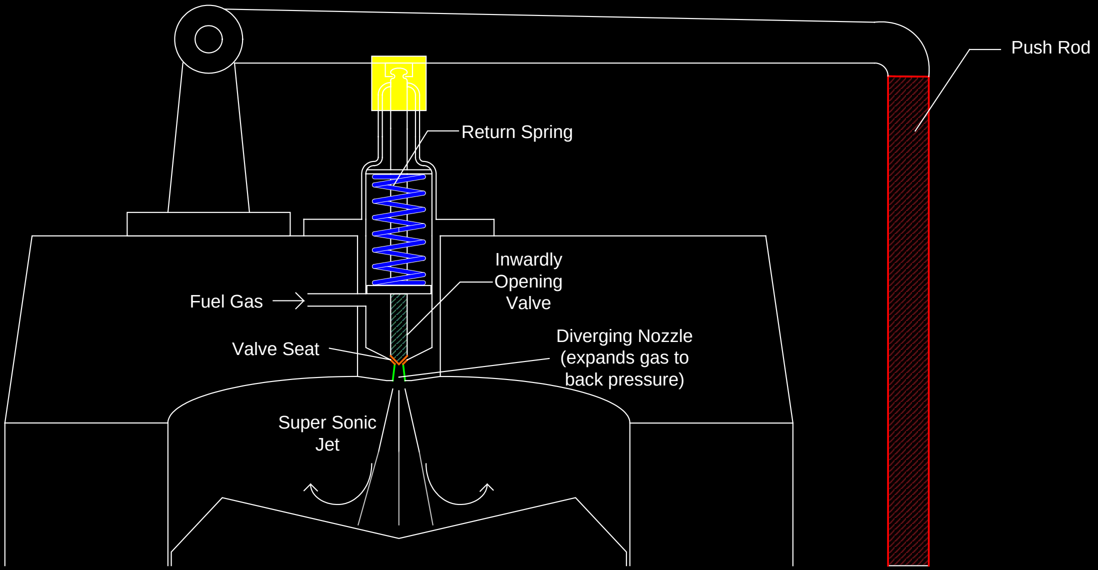
- Bi-weekly conference calls with CSU, Dresser-Rand, and Dominion
- Report on project at PRCI CAPSTC, May 10-12 in San Diego; will get input from entire committee
- Planned on-site focus meeting at D-R in Painted Post, NY – May 19
- At meeting will select technology develop technology commercialization plan

Task 1.4: Component Procurement & Fabrication:

Candidate Technologies for D-R Commercialization



Tuned Exhaust Manifold



Inwardly Opening Supersonic Mechanical Fuel Valve

Task 1.5: System Test Plan

- Expand simplified test plan presented earlier
- Detailed plan will include specific operating conditions, list of measured parameters, and list of test points

Task 1.6: Uprate Systems Installation

- Installation of uprate systems will begin once hardware is delivered
- Installation will be performed by CSU personnel with direction from manufacturers

Task 1.7: Uprate System Test

- Testing will commence once uprate systems are installed

Year 2 Project Schedule

Task	O 05	N 05	D 05	J O6	F O6	M 06	A 06	M 06	J 06	J 06	A 06	S 06	O 06
2.1 Selection of Field Test Unit	■												
2.2 Component Procure/ Fab		■	■	■	■	■	■	■	■	■	■		
2.3 Field Test Plan			■	■	■								
2.4 Component Procure & Fab					■	■	■	■	■				
2.5 Uprate System Field Install									■	■	■	■	■
2.6 Uprate System Field Test								■	■	■	■	■	■
2.7 Technology Transfer Plan								■	■	■	■	■	■
2.8 Annual Contractor Review												■	
Semi-Annual Progress Report							■						■