

# DARPA XV List of Components and Subassemblies

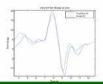
**NREC Team** 

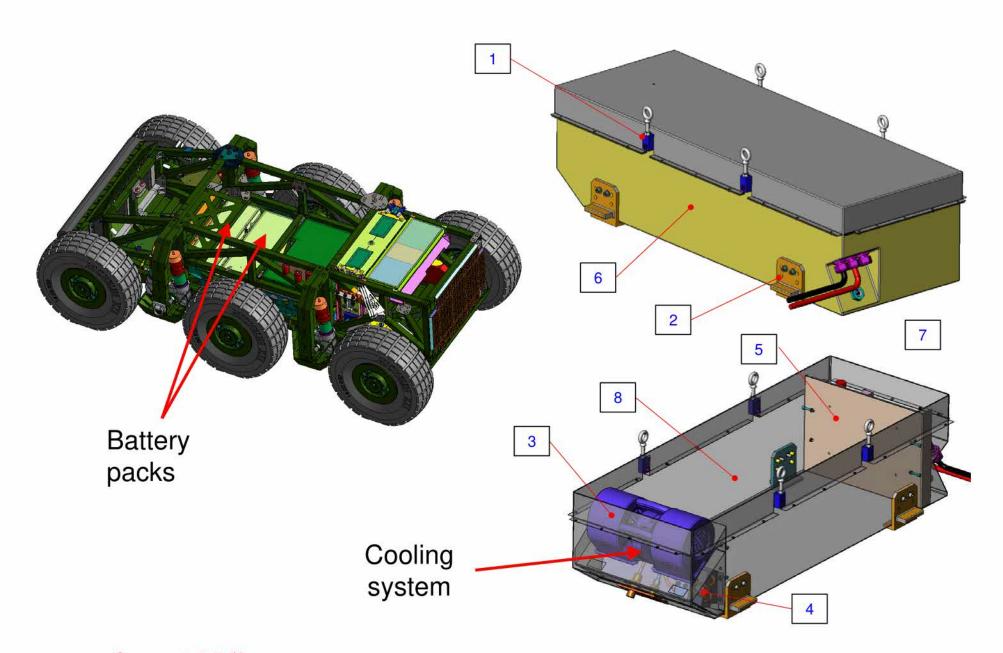
(b)(4); (b)(6)

Revision 2 – November 30, 2012



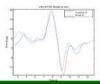
## **Battery Frame and Cooling**







#### **Battery Frame and Cooling System**



#### Components

- 4 integrated hoist points
- 2. 4 mounting brackets
- 3. Blower fan
- 4. Tube and fin heat exchanger
- 5. Electronics panel
- 6. Welded aluminum housing
- 7. Power cabling
- 8. Internal volume for batteries

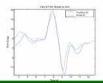
#### Description

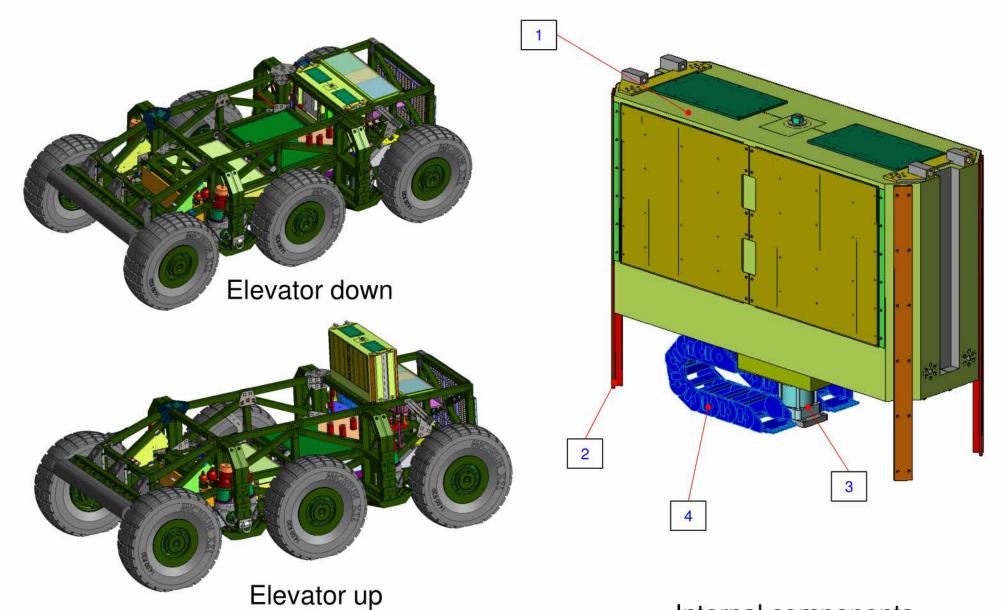
- → Battery pack to power vehicle
- → 2 packs per vehicle
  - Vehicle is capable of operating on only 1 pack
- → Typical current draw: 200A @ 350VDC
  - Occasional draws at 400A
- → OEM battery controller mounted with electronics panel
- → Cooling
  - Forced convection w/ refrigerant system
  - Air circulated within pack (like refrigerator)
  - Expansion valve and evaporator inside pack
  - Condenser external to pack
  - Removed heat load of 200W





## **Elevator Assembly**





Internal components





### **Elevator Assembly**



#### Components

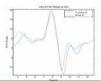
- 1. Aluminum enclosure
- 2. Guide rails for linear positioning
- 3. Pneumatic cylinder
- 4. Cable management

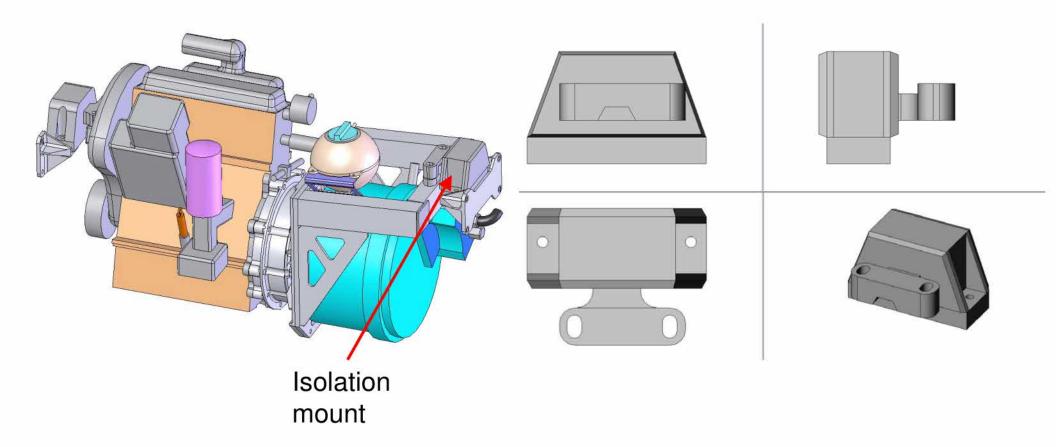
#### Description

→ Contains high & low voltage power and control electronics, rises out of vehicle for accessibility and maintenance



### **Power Pack Isolation**







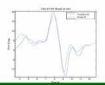
#### **Power Pack Isolation**

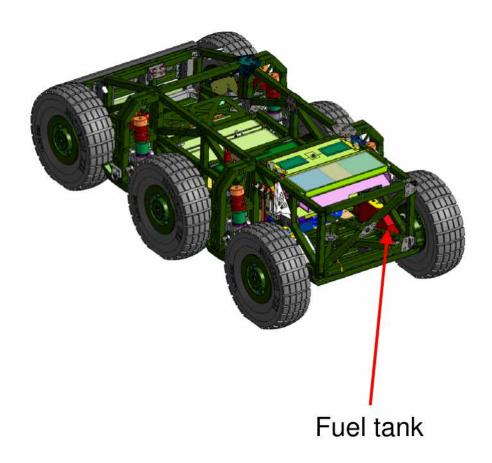


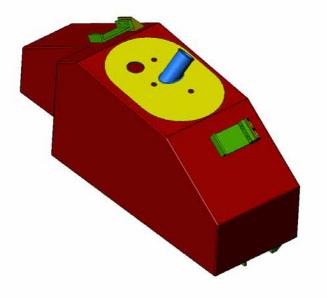
- Natural rubber and steel construction
- Weight 7.5 lb ea
- Load range 1300lb per
- Attenuation 12.5-10,000 hz
- Transmissibility 7hz



## **Fuel tank**

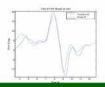








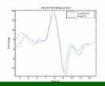
#### **Fuel Tank**

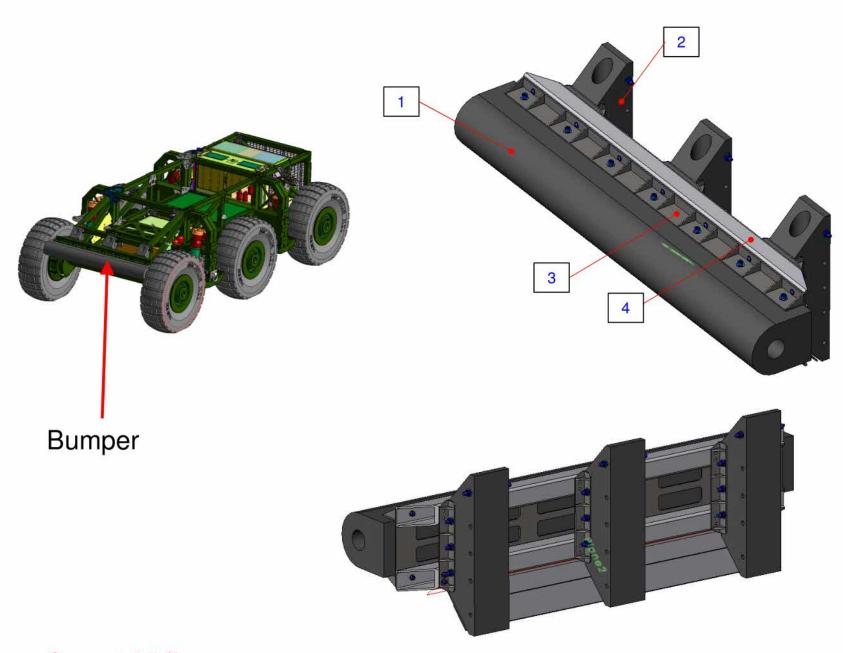


- See document DARPA-XV-Crusher-Model2-Nov2012
- Fuel cell manufactured by ATL



## Two stage bumper







### **Two Stage Bumper**



#### Components

- 1. Compliant EPDM rubber
- 2. Rigid EPDM rubber
- 3. Titanium weldment
- 4. Aluminum tube

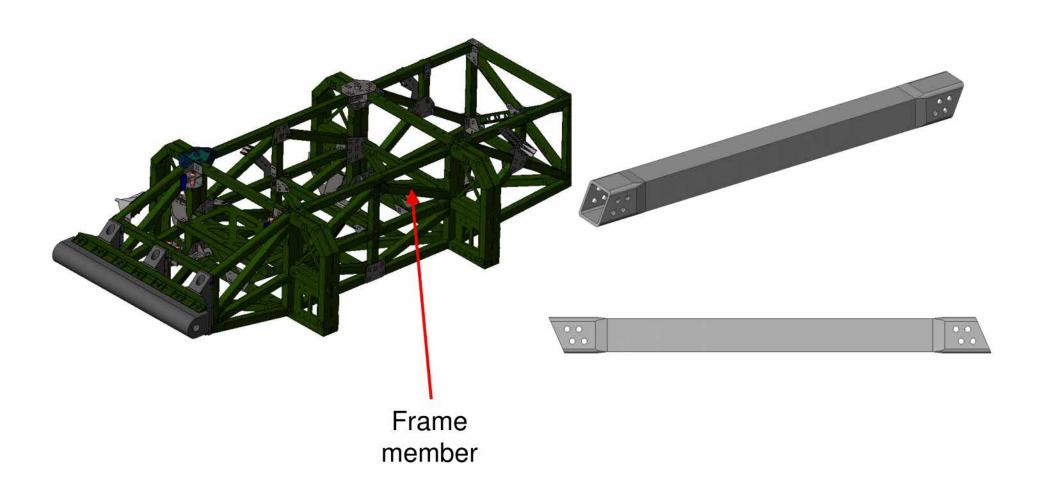
#### Description:

- → Purpose of bumper: knock over small trees (25cm) at full speed
- $\rightarrow$  2000N cm spring rate
- → 440kN impact at 11g



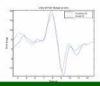
## **Frame Member**







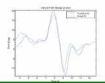
#### **Frame Member**

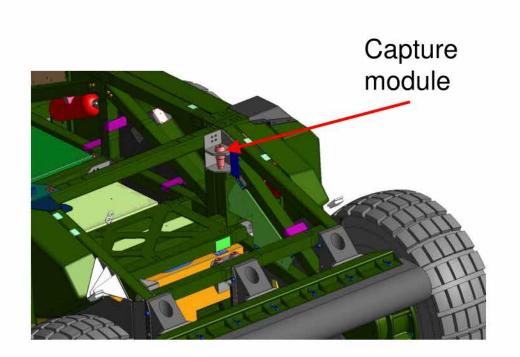


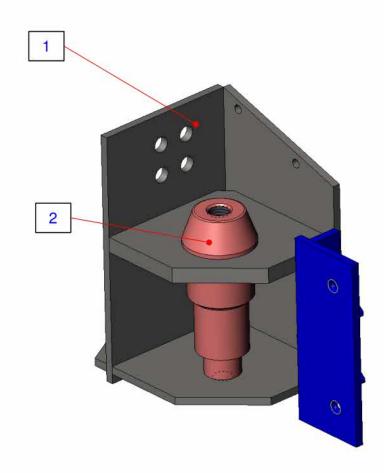
- Aluminum 2195
- 4 mounting holes each end
  - → Holes were reamed at assembly to titanium joining plates and secured with slip-fit shoulder bolts
- Machined (thinned in center section) for weight reduction



## **Frame Capture Module**









## **Frame Capture Module**



#### Components

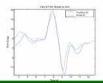
- 1. Titanium weldment
- 2. 4340 steel pin

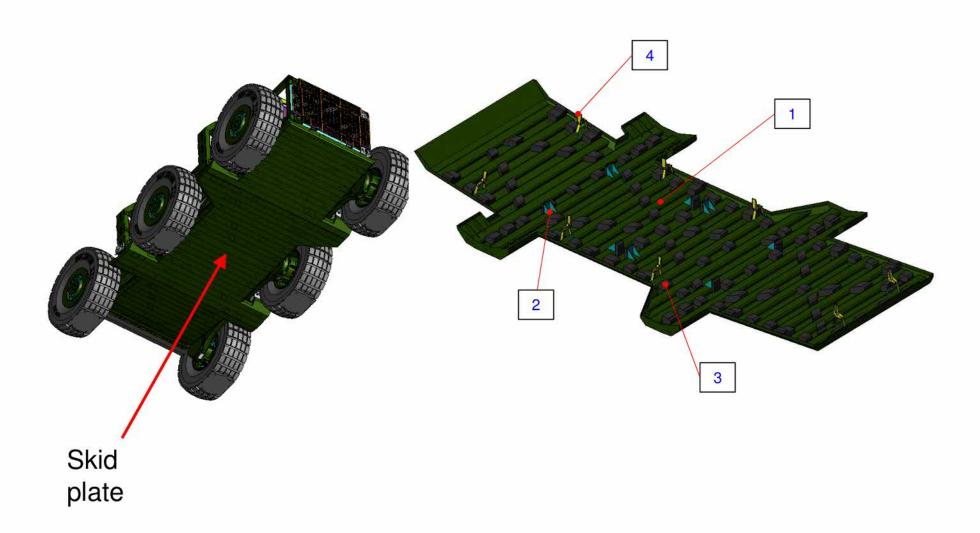
#### Description

- → Mounting point for perception module
- $\rightarrow \textbf{Conical for self-alignment}$



## **Skid Plate**







#### **Skid Plate**



#### Components

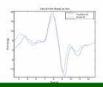
- 1. Hardox 450 steel weldment
- 2. Longitudinal brackets (steel)
- 3. Rubber pads
- 4. Mounting straps (wrap around frame)

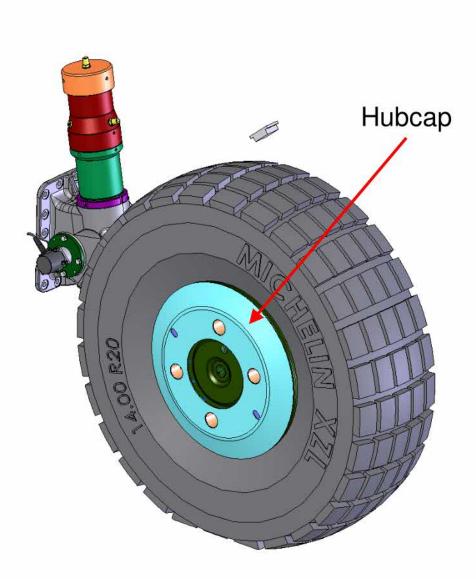
#### Description

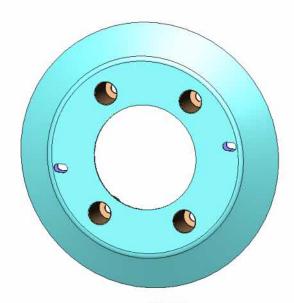
- → Designed to protect for running over rocks
- → 18mm stroke (rubber compression)

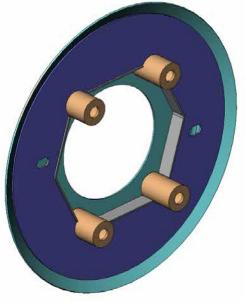


## **Hub Protection**



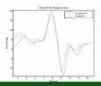








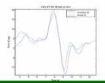
## **Hub Protection**

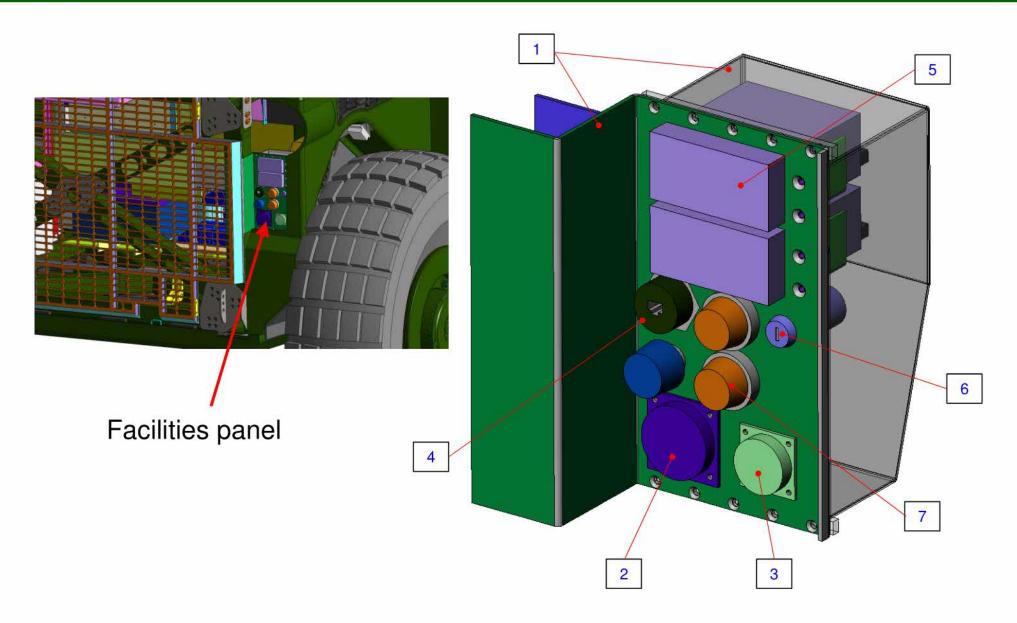


- · Steel weldment
- Designed for 200kN side force from sliding into obstacle
- · Protects center hub



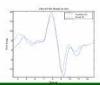
### **Facilities Panel**







#### **Facilities Panel**



#### Components

- 1. Aluminum enclosure and mounting
- 2. 350V connector
- 3. 24V, 12V, 5V connectors
- 4. Ethernet port
- 5. Displays
- 6. Key switch
- 7. Indicator lights

#### Description

→ Interface for charging, data interface, and vehicle startup

#### **Hydro Strut Component Documentation**

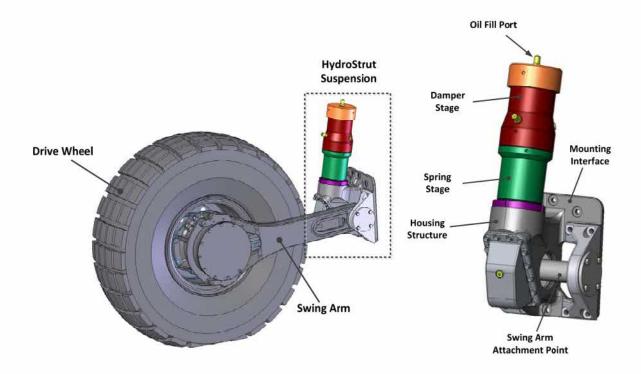
(b)(4); (b)(6)

**National Robotics Engineering Center** 

(b)(4); (b)(6)

#### Overview

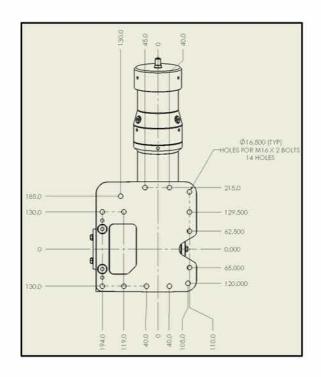
This document gives the physical and dynamic properties for the hydro strut suspension component used in the Crusher vehicle. The goal of this document is to provide enough information for the component to be integrated into the AVM component library.

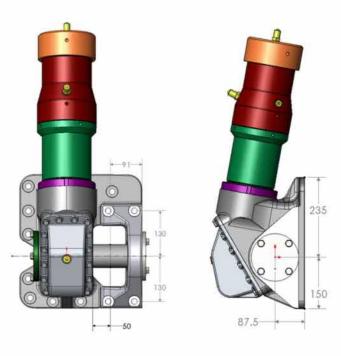


In the system diagram above, the hydro strut suspension component is used to connect to the swing arm component of a drivetrain, which is subsequently connected to the drive wheel. For this analysis, the hydro strut suspension component is separated from the rest of the drivetrain. Its physical and dynamic properties are given so that it can be characterized on its own so that it can easily be integrated into system design.

#### **Physical Properties**

The hydro strut is made of several major subcomponents. The swing arm assembly connects to the hydro strut assembly via the swing arm attachment point (2 5/8" diameter steel shaft). That shaft then acts on several internal components that provide spring and dampening force as the axle rotates. The component is mounted onto an assembly via several bolts on the rear side of the mounting interface.





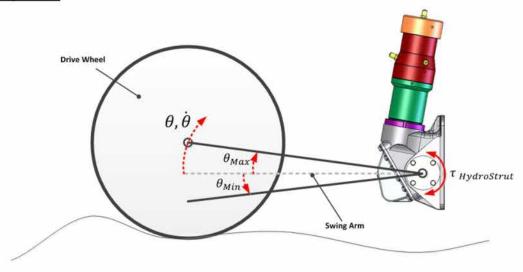
These holes are 16.5 mm bore diameter to allow for the installation of 16mm diameter bolts, with their locations described in the picture above (to the left). Additionally, the location of the shaft where the swing arm mounts is described in the picture above (to the right). The layout of the bolt-hole pattern and shaft location are shown with dimensions in mm.

The mounting interface and hydro strut structure was built out of several cast carbon steel components that are assembled together. It can be assumed that the mechanical properties for the load bearing members of the component to follow the data in the table below:

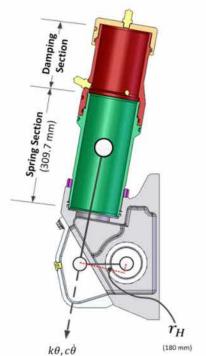
Elastic Modulus	2.00E+11	N/m^2
Poissons Ratio	0.32	N/A
Shear Modulus	7.60E+10	N/m^2
Density	7800	kg/m^3
Tensile Strength	4.83E+08	N/m^2
Compressive Strength in X		N/m^2
Yield Strength	2.48E+08	N/m^2
Thermal Expansion Coefficient	1.20E-05	/K
Thermal Conductivity	30	W/(m·K)
Specific Heat	500	J/(kg·K)
Material Damping Ratio		N/A

The hydro strut component assembly model is simplified and does not contain many internal components (bearings, linkages, etc.). The overall weight of the full component that would be integrated can be assumed to be 50 kg.

#### **System Dynamics**



When integrated into a drivetrain suspension, the hydro strut component will provide resistive loads onto the swing arm as it reacts against changing road / ground conditions. The swing arm is able to move radially about the swing arm attachment point of the hydro strut. It can be assumed that the



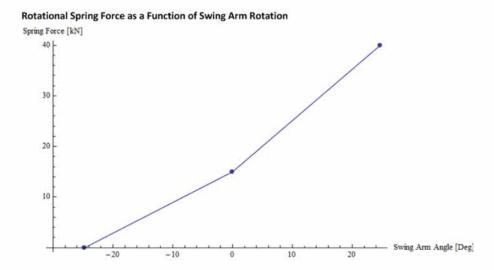
natural "zero" position of the swing arm is parallel to level ground. The swing arm is able to move radially to a maximum and minimum angle ( $\theta_{Max}, \theta_{Min}$ ). For the example component,  $\theta_{Max} = 25.2$  °and  $\theta_{Min} = -25.2$  °

As the swing arm rotates, it causes the shaft within the hydro strut to rotate at the same rate. Internal to the component, a linkage system connects a linear spring and damper system to the swing arm connection shaft (as shown in the image to the left). The linear spring and damping forces are then translated into a reactive torque load about the swing arm connection shaft due to the linkage offset,  $r_H$ . For this assembly, the value of  $r_H$  is 180 mm.

The spring force for the hydro strut has two distinct linear values depending on the rotation of the swing arm. Due to the nature of the linear spring and the preload in the system, the linear spring force is estimated to be

$$F_k = \begin{cases} 0.6073 \,\theta + 15 & \theta \le 0 \\ 1.0122 \,\theta + 15 & \theta > 0 \end{cases} [kN]$$

The spring force can also be described in the following graph.



The damping force for the component depends on the direction of the angular velocity of the swing arm.

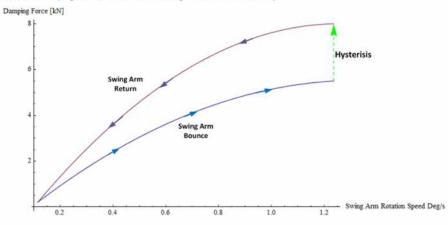
Positive angular velocity refers to "swing arm bounce" motion whereas negative angular refers to "swing arm return". The relationship between angular velocity and damping force is estimated (using a  $2^{nd}$  order polynomial fit) to be

$$F_c = \begin{cases} -3.622 \,\dot{\theta}^2 + 9.617 \,\dot{\theta} - 0.853 & Bounce \\ -5.991 \,\dot{\theta}^2 + 15.044 \,\dot{\theta} - 1.443 & Rebound \end{cases} [\text{kN}]$$

It is important to note that the magnitude of the angular velocity is used to estimate the damping force and the sign of the velocity only determines the mode in which it is operating. Also, there is a noticeable amount of hysteresis during operation between the bounce and return modes of the damper.

The damping force can also be described in the following graph.

#### Rotational Damping Force as a Function of Swing Arm Rotational Velocity



Using the derived values for the spring and damping force, a general relationship of the dynamic torque applied to the system from the hydro strut component can be described as

$$\tau_{Hydrostrut} = (F_k + F_c) r_H$$

#### **System Variability**

The hydro strut component can be adjusted to accommodate different angular ranges of motion as well as varying spring and damper rates. The spring section of the hydro strut component can be elongated or shortened to change the range of motion of the swing arm. With the component model used ( $\theta_{Max}=25.2\,^{\circ}$  and  $\theta_{Min}=-25.2\,^{\circ}$ ) in this analysis, the spring section has a total length of 309.7 mm. Of that length, 169.4 mm is taken up in the linear motion of internal elements leaving 140.3 mm in supplementary support structure. A generalized relationship can be derived that gives the adjusted spring section length based on varying  $\theta_{Max}$  and  $\theta_{Min}$  as shown below. Note that angles are in degrees and lengths are in mm.

$$L_{SpringSection} = (\tan|\theta_{Max}| + \tan|\theta_{Min}|) \times 180 + 140.3 \text{ (mm)}$$

The other factors that can be adjusted in the component are the spring and damping rates. This component varies the spring rate by changing internal components that does not affect the external geometry of the system. Therefore, it can be assumed that the spring and damping rates can be scaled to accommodate a wide range of options for use in drive train systems. The characteristic shapes of how the spring and dampers act in the system will not change, though.

#### **Supplementary Materials**

A STEP file of the hydro strut assembly is included with this report packet.

If there are any questions or complications, please contact:



Carnegie Mellon University, Robotics Institute National Robotics Engineering Center 10 40th Street, Pittsburgh, PA 15201, USA Tel. (b)(4); (b)(6)



Carnegie Mellon University, Robotics Institute National Robotics Engineering Center 10 40th Street, Pittsburgh, PA 15201, USA Tel. (b)(4), (b)(6)

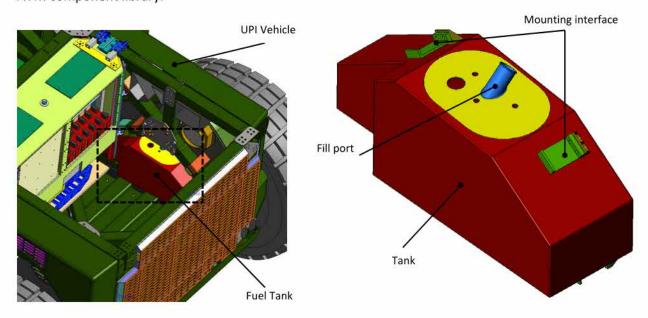
#### **Fuel Tank Documentation**

(b)(4); (b)(6)

National Robotics Engineering Center (b)(4), (b)(6)

#### Overview

This document gives the physical properties of a fuel tank component used in the Crusher vehicle. The goal of this document is to provide enough information for the component to be integrated into the AVM component library.



The fuel tank shown above supplies fuel to the vehicle power pack. For this analysis, the fuel tank is separated from the rest of the vehicle. Its physical properties are given so that it can be characterized and easily integrated into system design.

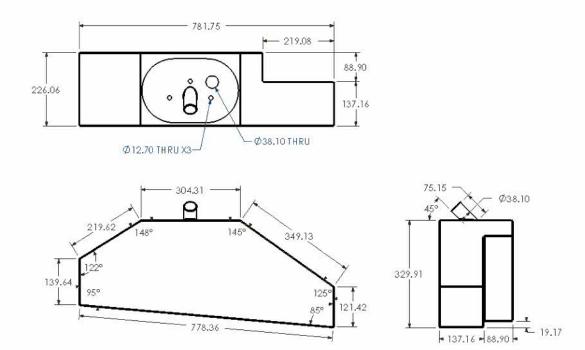
#### **Physical Properties**

The fuel tank consists of very few components. The tank is made of 1/16 inch 6061 aluminum sheet, which is fully welded at all seams to contain liquid fuel. The mounting interface consists of 6061 aluminum machined angle brackets welded to the tank, which interface with clips that mount to the vehicle frame. The clips are mounted using ½-20 bolts.

The fill port on the top of the tank is made of aluminum and welded to the tank. There are additional ports on top of the tank for connecting fuel lines to the power pack and fuel level monitoring.

#### **Dimensions**

Dimensions of the fuel tank are shown below. The tank has a volumetric capacity of 39.3 liters.



#### **Supplementary Materials**

A STEP file of the hydro strut assembly is included with this report packet.

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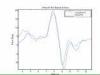
(b)(4); (b)(6)

Carnegie Mellon University, Robotics Institute National Robotics Engineering Center 10 40th Street, Pittsburgh, PA 15201, USA Tel. (b)(4); (b)(6) (b)(4), (b)(6)

Carpagia Mallon University

Carnegie Mellon University, Robotics Institute National Robotics Engineering Center 10 40th Street, Pittsburgh, PA 15201, USA Tel. (b)(4); (b)(6)





## Experimental Vehicle (XV) Model Overview

17 May, 2012

(b)(4); (b)(6)

Carnegie Mellon University

National Robotics Engineering Center

Ten 40<sup>th</sup> St.,

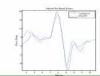
Pittsburgh, PA 15201

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(b)(4); (b)(6)







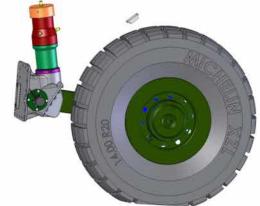


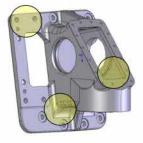




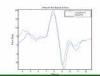
- NREC Overview
- Experimental Vehicle (XV)
   Overview
- Design Methodology @ NREC
- Type & Identifier of Parts /
   Assembles (Time Permitting)
- Example Case (Live Cad Model)













- 6000 undergrad; 5400 grad
- \$865M operating revenue
- \$318M sponsored projects

School of Computer Science

Robotics Institute



- ~ 450 faculty, staff, grad students
- · MS and Ph.D in robotics
- \$56M sponsored projects

National Robotics Engineering Center



- 120 faculty, staff, grad students
- ~70% Staff
- ~\$29M sponsored projects

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**Today** 

**Future** 







## Total State Control of the Control o

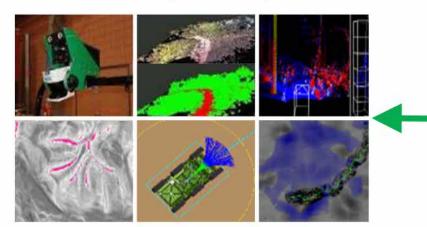
#### Defense, Mining, Agriculture, General Industry



#### Integrated Platform Development & Evaluation



**Autonomy & Perception** 



## **Smart Teleoperation & Vehicle Safety Systems**



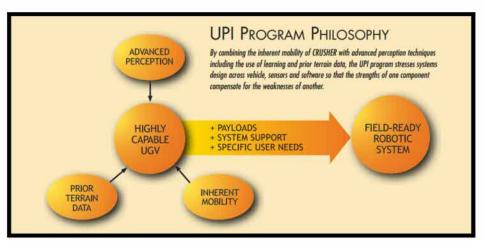






### **Experimental Vehicle Overview**





UGCV ("CRUSHER")



**PerceptOR** 



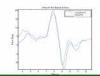




**UGCV PERCEPTOR INTEGRATION (UPI)** 







## **UPI: Highly Mobile Autonomous Robotic Vehicle with Perception and Intelligence**





Unloaded vehicle weight	13,200 lbs	
Maximum payload/armor	8,000 lbs (maintaining capability)	
Length	201 in	
Width	102 in	
Height (w/16 in ground clearance)	60 in	
Ground clearance	0-30 in (reconfigurable)	
Tire diameter	49.5 in	
Top speed	26 mph (<7secs)	
Minimum turning radius	O (skid steer)	
Slope climbing	>40 deg (traction limited)	
Side slope	>30 deg (traction limited)	
Step climb	>4 ft	
Gap/trench crossing	>80 in	
Engine	Turbo diesel	
Generator output	58 kW/78 hp	
Onboard battery storage	18.7 kW-hr energy	
Traction motors	210 kW/282HP continuous	
Peak torque	40,000 ft-lb (6WD)	
Payload volume (internal)	41.6 ft <sup>3</sup> main bay (inside hull)	
rayload volume (internal)	16.1 ft <sup>3</sup> front bay (inside hull)	
Payload power	28V, 5kW	
rayload power	300V, 10kW	
	Wireless pendant control (RC)	
Control modes	Teleoperation control	
Control modes	Waypoint following	
	Full autonomy	







#### **CAD Representation: UPI**







Native CAD Program: SolidWorks

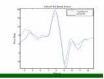
**Number of Unique Parts: 1483** 

**Total Number of Components: 5850** 

Number of Sub Assemblies: 352

Maximum Depth of Sub Assemblies: 5







#### **UPI TOP LEVEL ASSEMBLIES**

**SKIDPLATE** 

**FRAME** 

**WIRE HARNESS (ROUTING)** 

**BATTERY COMPARTMENT** 

**BRAKING SYSTEMS** 

**FUEL SYSTEM** 

**HIGH VOLTAGE SYSTEM** 

AIR CONDITIONING

ELEVATOR SYSTEM
(LOW VOLTAGE COMPUTING)

**EXTERIOR COVER PLATING** 

**PERCEPTION SYSTEMS** 

**SUSPENSION & DRIVE SYSTEMS** 





NO.	DESCRIPTION	atv
	UPL Concession  LPT SUBPLINES ON 2	
W.	DECEMBER ASSESSED	100
1	ORLES	- 177
1	Brook / Nectoriosalem	1
7	FIRE DOWNERS .	100
-	REMI PACECTED CREEK	
7	WHETE WELL CONTO ASSEMBLY ROUNNEAD ASSEMBLY ROUNT, FRONT	
10	5P0811	-
	SPORSON ASSEMBLY, FRONT, LBTT	
u u	SPONSON, LEFT, MIDDLE. ACCIDENCY	13.
19	SPORSON BILLHERO, LOTT, REAR. ANEMBLY	2.4
18	SPONSON ASSOME'S BROWN. MICOLE	177
19	SPONSON ASSESSED, NIGHT PROSE	- 10
11	ELEPTER ASSISSON NOT BACK	- 1
-0	SPONSON ASSENSOR FROM REAL	100
0	SPONSON ASSENDED. RESPERTANT	
и	IBOLATIONIADIANT, PLANSEN, ASS	100
(ii)	MA. I. Art BLEWICK	T.W.
W.	WWW.RET I, ANT BUTWING MA, SUPPORT	1.7
8	SUPPORT BRACKET, LOWER AFT ELEVATOR ASSY	174
4	ASSY SCREW 38 IS FOR CORPOR	- 1
20	SCREW, 28-10 A DALLO SHOS BRADNET L. LOWER AFF ELEVATOR ASSY	17
26	RALL ATT, ELEVATOR	7.1
38	FALL ATTEMATOR  BLACKET L ATTEMATOR SAAL  SUPPORT	17.0
т.	SLAURTOR REST	5.4
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(2)	BINNETON	
	ERRORET, CONCRETORE, ELEVATOR	20.0
30	MAL SURVIVE GEOR, FRANCE  MONEY COMMENT ON THE SERVICE  MAL SURVIVE GEORGE FRANCE  GEORGE FRANCE  GEORGE FRANCE  GEORGE FRANCE  FRANCE GEORGE GEORGE  FRANCE GEORGE  FRANCE GEORGE GEORGE  FRANCE GEORGE  FRANCE GEORGE GEORGE  FRANCE GEORGE  FRANCE GEORGE  FRANCE GEORGE GEORGE  FRANCE GEORG	2.7
	STRUCTURE	1.1
9K	PLATE, GUS DECK, ELEMATORI  GRACHET, LADER GLAMMEL	- 1
_	DEWIOR .	-
	ETHLETIJNE, MENON	31
9	DODOWN THE REST. SECRETOR	
(8)	AUTO ENTTERY BOX	125
M	BRACOST, MATTERY TO CHARGES, RESULT	8.3
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5	BLOCK BATTERY RICEINE CLAWP	- 2
40	OATTER FACE IN SPAREE OF HOW FOLL PACE ENCLOSURE, 2 O FUEL DARK, PROPET AUX	- 1
*		
	FUEL TWYK RIGHT	3.9
4	DARCK DISCONNECT ASSIST	7.0
-	PLATE, DRIER REPYTHY	- 1
	RECEIVER PREH	- 1
-	COMPANY ASSEMBLY AC	
*	CARLE THAY BARE NORT, MODILE	-1
9	SPANE ACCUMULATOR ASSEMBLY	123
M C	MANY PRINT, LEFT	2.7
	FAREL BUNGLEGAT	17
	FLATE, ADMPTER, NODE, PER, ADMPTER, NODE	
-	REPLACEMENT	_
	BHANET LOWERELD WHO STOP	1.6
2	SEPTORE CLOSUR SOLATOSCIPIR.	- 1
*	SUPPORT 2.LOWER ISSULTION, FEB.	
69		238
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# 1	DETING LUE, STOCK	10.1
п	FORMBOOKEE, AN 20	- 1
66	BROWET & NY CAS WIS 28	1/4
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W.	SCHEW, 42 K 12 LIS SHOULDERS SCHOOL	.0
50	BNACKT FORE INVAFFORT BNACKES AFT BY BUFFORT 1	- 1
III.	WACKET, AFT, HE WATER 1 PROPERTY OF 2 NA POPERTY	(1)
77	ELECATOR, PERCEPT DALZE HISSE TRANSPLE DALZ	
77	RACE PROMOTE CAUSES NOA	0.4
N.	BHW 21CA RML ALBEMIEY	174
8	AACS, THICSUPPORT, PURKERTION:	1.1
n	PLATE, FRONT CYLINDES SUPPORT E.S.	- 1
-77	BUSSET LIPER RAY, SUPPORT BENEZION LICELER MYS. PER	- 1
10		
75	Roselleys John Lose on	100
		- 1
W.	FLC#Tings_Xbar1, z/+ ca	- 1

NO.	DESCRIPTION	QTY.	Process
11:	UPI_Suspension	3	Assembly
1.1	HYDROSTRUT BEARING ASM	1	Assembly
1.2	HYDROSTRUT BEARING ASM, 2	- 1	Assembly
1.3	SUSPENSION STRUT MOUNT	- 1	Assembly
1.4	135ID X 5 ORING, STOCK	1	Stock
1.5	SEAL, QBAR04426	1	Stock
1,6	M16 X 2 X 40 FLATHEAD SCREW, STOCK	2	Stock
1.7	BACKING PLATE, BEARING BLOCK 2	1	WaterJet
1.8	M10 X 2 WASHER, STOCK	8	Stock
1.9	M10 X 1.5 X 30 HEX HEAD SCREW, STOCK	8	Stock
1.1	BEARING CAP, MACHINED	1	Machined
1,11	HYDROSTRUT OUTER CASE	1	Casting, Machined
1.12	SPANNER NUT, KML 28, STOCK	1	Stock
1.13	HYDARULIC VALVE, EMA 2- 2_8EDA3C, STOCK	2	Stock
1:14	HYDRAULIC PLUG, VSTI3-8ED	4	Stock
1.15	ACCESS COVER, HYDROSTRUT, MACHINED	.1	Machined
1.16	M8 X 1.25 X 25 HEX HEAD SCREW, STOCK	16	Stock
1.17	M8 X 1.6 WASHER, STOCK	16	Stock
1.18	LIMIT STOP BLOCK, HYDROSTRUT, STOCK	1	Machined
1:19	HYDROSTRUT MIDDLE CASE	(1	Casting, Machined
1.2	HYDROSTUT CASE TOP CAP	1	Machined
1.21	RING SEAL, V7T41, STOCK	- 1	Stock
1.22	SWING ARM AND WHEEL COMPONENTS (ASSEMBLED)	21	Assembly
1.23	1400_R20_XZL_TIRE, MICHELIN, STOCK	1	Stock
1.24	Celesco RT8510-0R50-1X1-1120- 632114A Transducer 180	- 31	Stock
1.25	SUSPENSION POTENTIOMETER MOUNT	1	Waterjet

#### **UPI Bill of Materials**

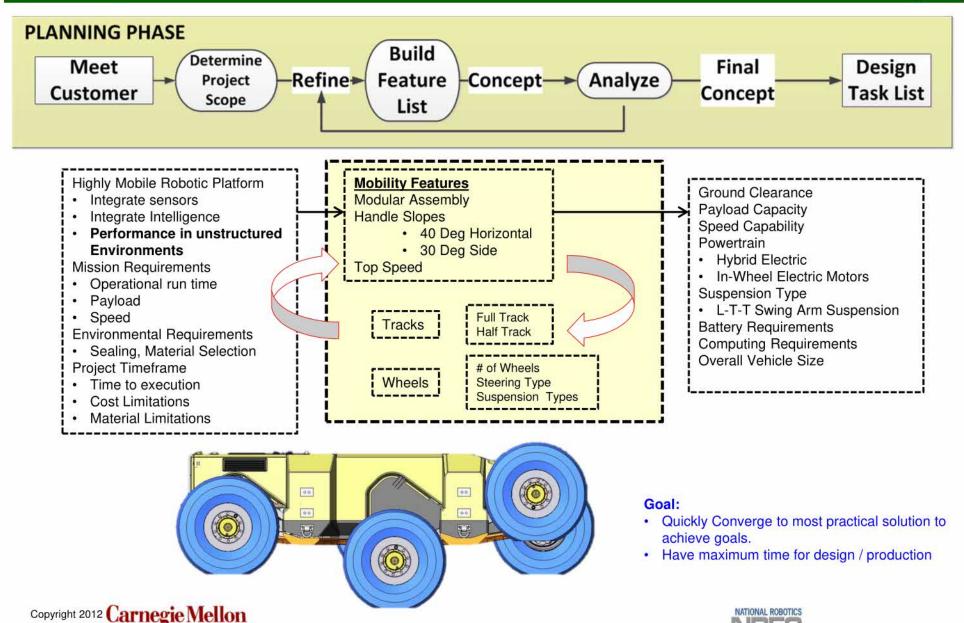
- · Excel Format Table
- · Directly Exportable from SW
- · Can contain multiple metadata fields
- · Nested sub-assembly structure

ITEM NO.	DESCRIPTION	QTY.	Process
1.25	SUSPENSION POTENTIOMETER MOUNT	(1	Waterjet
1.25.1	WASHER, #8 FLAT NARROW (3/8 OD)	6	Stock
1.25.2	SCREW, #8-32 X 3/8 LG SHCS	6	Stock
1.25.3	HYDROSTRUT BEARING BLOCK 2 OUTER CASE	3	Machined
1.25,4	OUTBOARD JOURNAL, 30_03_05	3	Stock
1.25.5	BEARING SEAL, TIM POT	(4	Stock
1.25.6	POTENTIOMETER, ROTARY SENSOR	- 1	Stock
1.25.7	OIL LIP SEAL, 1/2" SHAFT, 1 1/4 BORE, 1/4 THK	31	Syock
1.25.8	SHAFT, LONG POT, UPI	1 1	Stock



#### **Design Process**







## **Design Process: Space Claim**

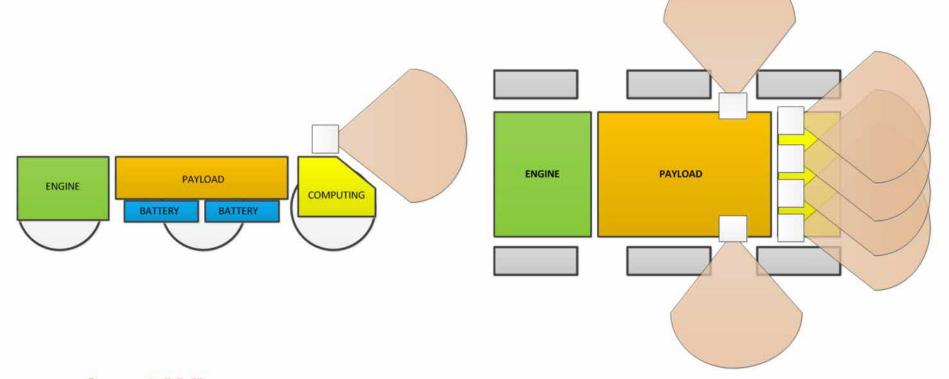


#### Space Claim Driving Factors:

- Known / Preselected Components
- Vehicle Dimension
- Ground Clearance
- Sensor Placement / FOV
- Payload Requirements
- Weight Distribution

#### Component Selection Preferences

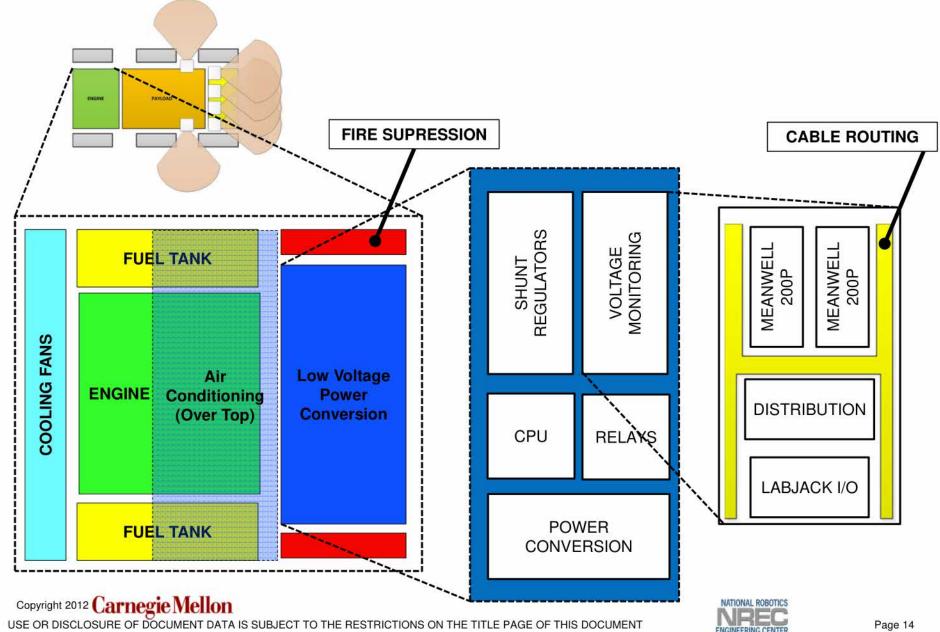
- 1. Lead Time
- 2. Performance
- 3. Dimensionality
- 4. Cost





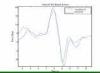
## **Design Process: Detailed Space Claim**

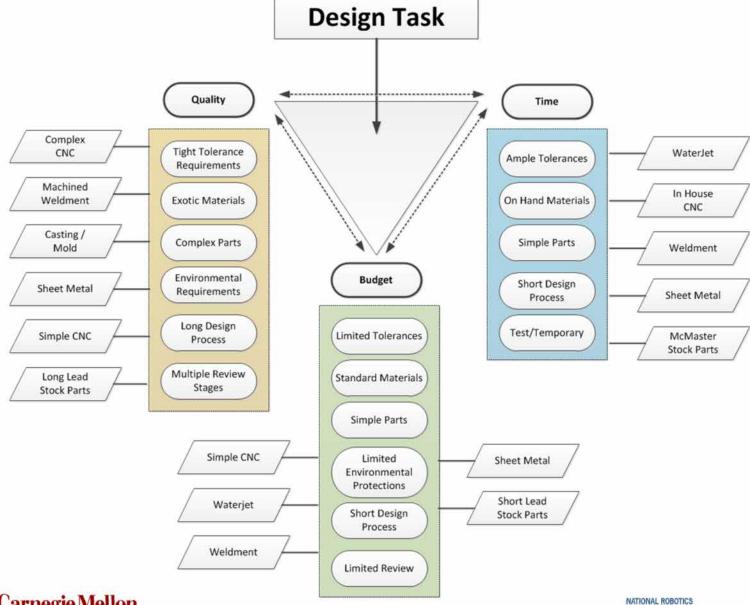






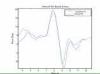
## **Design Decision Tree**

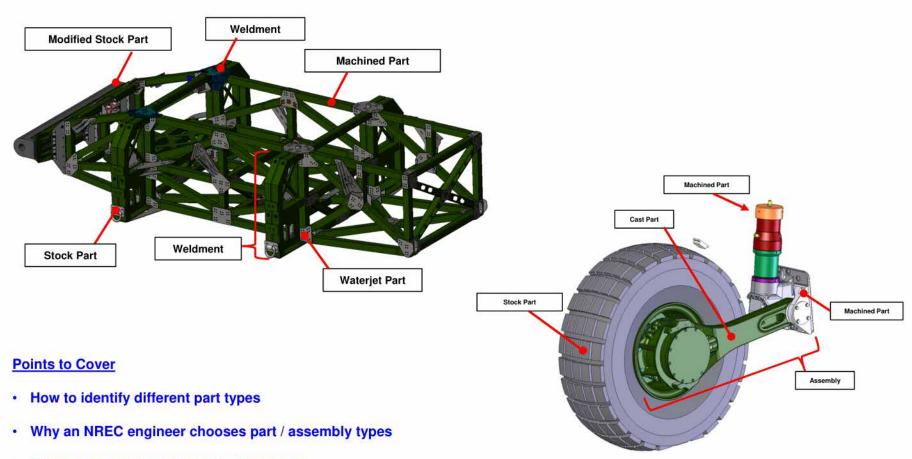






## **Part & Assembly Identifiers**





· What are lessons learned / best practices



#### Part & Assembly Identifiers: Meta-Data



#### **META-DATA (NEW PART – NREC Standard)**

- Used to populate fields on part drawing sheets
- Used to keep files organized in file management system

	Property Name	Туре	Value / Text Expression	Evaluated Value	
1	FINISH	Text	▼ SEE NOTES	SEE NOTES	NATIONAL ROBOTICS
2	MATERIAL	Text	→ SEE NOTES	SEE NOTES	ENGINEERING CONSORTIUM DESCRIPTION
3	REV	Text	▼ 0	0	TEN 40% STREET PETERLINGEN PA 16201
4	AUTHOR	Text	→ AUTHOR	AUTHOR	DRAWN ST: CREATED SIZE PART NUMBER: REV
5	DESCRIPTION	Text	→ ENTER DESCRIPTION	ENTER DESCRIPTION	CHICARY EPPONS A
6	AUTHORFULL	Text	→ AUTHORFULL	AUTHORFULL	THE RECOMMEND OF THE DESCRIPTION OF THE DESCRIPTION OF THE PROPERTY OF THE PRO
7	PART NUMBER	Text	▼ PART NUMBER	PART NUMBER	The Recommendance Conference Co
8	<type a="" new="" property=""></type>				HOMERO THREE PLACE DECIMAL 1 JOS SPIEEL I OF

Author / AUTHORFULL: Part drawing creator, sometimes "N/A" if not a custom part

(ex: G.J.G, G. GOLDMAN)

**Description:** Description of part type, machining type, and location in sub-assembly

(ex: Node\_Plate,Corner\_Node\_Weldment,Frame\_Assmebly)

Part Number: Designator of part. Can be either custom part number or stock company's stock number.

(ex: UPI-0236, MMC 2994T69)

Rev: Design revision of part. Usually only associated with custom parts (@ NREC)

Material: Base material of part. Usually left as "Stock" for stock components.

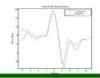
(ex: Aluminum, 6061, Carbon Steel, Delrin)

Finish: Used if a special material finish is required.

(ex: Black Anodized)



#### Part & Assembly Identifiers: WaterJet / LaserCut/ EDM



#### Part Geometry Identifiers – WaterJet / LaserCut/ WireEDM

- · Slot and Tabs
- · Planar components
- · Hard edge or rounded cut-outs
- · Holes & cut-outs are completely through part

#### **Design Benefits**

- · Low Cost
- · Easy to Modify
- · Very Quick
- Easily Scalable
- · Large Selection of Materials
- · Part Thickness
- · Can have hard edges internal to part

#### **Design Considerations**

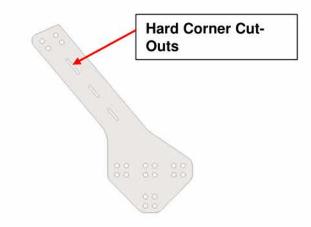
High tolerance stack up

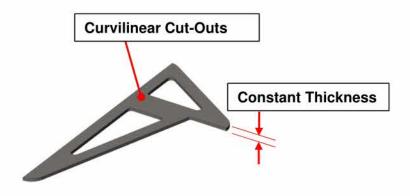
- Extra clearance for ALL holes / slots / tabs
- · Gap in between welded edges

Warping in thin parts

Conical cuts require touch up pass for bored holes

- · Undersize holes that need to be exact tolerance
- · Either post machine or hand bore









#### Part & Assembly Identifiers: CNC Mill / Molding / Casting

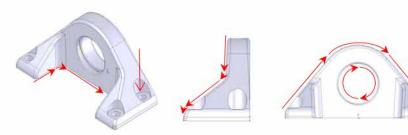
#### Part Geometry Identifiers - CNC Mill / Injection Mold / Casting

- · Non-Planar features
- · Curvilinear cut-outs
- · Rare to have hard internal edges on cut-outs
- · Features are formed from milling on multiple faces
- · Usually orthogonal faces are used for milling surfaces
- · Edges usually have fillets or chamfers
- · Blind holes can be created using mill plunges
- · Specialty mills can be used
  - → Undercutting
  - → Chamfering
  - → Radius
  - → Taps
- · Standard mills used for many features
  - → Minimum radii on cuts
  - → Standard fillet radii
  - → Tapped holes have standardized sizes
- It is difficult to determine the difference between injection molding, casting, and CNC milled parts by geometry alone.
  - → Materials could give insight
  - → Other metadata should give designator for part type

#### **Design Benefits**

- · Parts can be post machined to make changes
- · Wide selection of metals and plastics
- · Good tolerances (at a cost)
- Quick turnaround
  - · In House Machine Shop
  - · Relationships with External Shops
  - Pay our way out of time crunch (+30-50% cost)

- Mindful of clearances between machined & stock parts
- Limit to standard sized CNC tools
- Specialty bits → more cost & time
- · Design part to use standard tool dimensions
- Non-orthogonal planes → \$\$\$
- Hard to do complex internal features





#### Part & Assembly Identifiers: Injection Mold / Casting

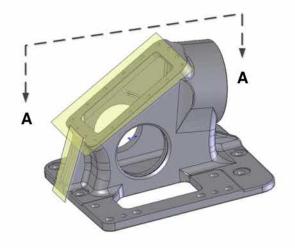
## Part Geometry Identifiers –Injection Mold / Casting

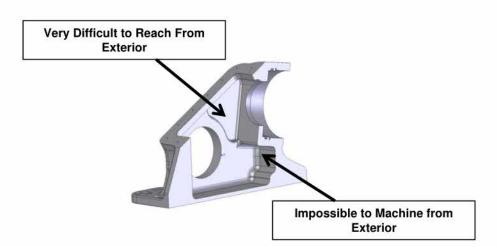
- · Very similar to CNC Milled parts
- Has more interior features that would normally be reachable with standard mills
  - → Pockets
  - → Bosses
  - → Mounting points
- · Has more non-orthogonal planes
  - → Would greatly increase set-up costs for CNC parts
  - → Each new plane is a new set-up that might required jigging parts on CNC

#### **Design Benefits**

- Material Control
- · Very complex geometries (internal & external)
- · Costs scale well for large quantities
- · Non planar features
- · Easier to optimize for loads

- · Longer engineering effort to design part and process
- · Will most likely require post machining
- Long lead time
- Not efficient in small quantity





#### Part & Assembly Identifiers: Sheet Metal

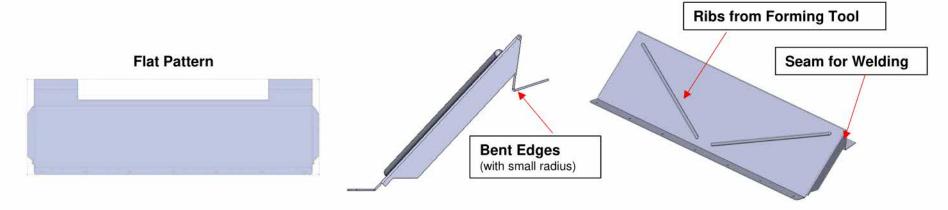
#### Part Geometry Identifiers - Sheet Metal

- Could be both planar and non-planar versions of the same part
  - → Planar part is cut on laser cutter or waterjet
  - → Forming tools then shape it into a non-planar part
- · Most edges have some curvature to them
- · Consistent thickness on parts
  - → Some stamping and cold drawn parts will reduce thickness when new geometry is created
- Stamped and formed features usually use standard tools.
- Sheet metal parts could initially have un-connected edges that are connected post machining / forming
  - → Welding
  - → Rivets
  - → Fasteners

#### Design Benefits

- · Quick Lead
- · Low Cost
- · Scalable Geometry
- · Non planar features
- Easily Integrate Hardware (PEMnuts)
- · Can integrate into weldments

- Load Capacity
- Limited to geometries that produce flat pattern
- Limited Material Selection
- · Limited part thickness
- · Heat management during welding
- · Allow for loose fit at mount points



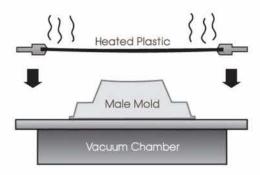


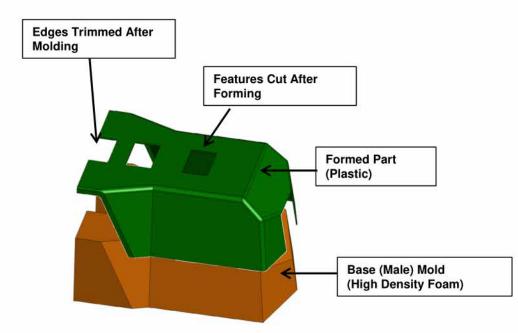
## Part & Assembly Identifiers: Vacuum Mold



#### Part Identifiers - Vacuum Mold

- · Usually plastic material types
- · Consistent part thickness
- · Usually has a main cavity volume where part was molded
- · Edges do no have seams or gaps
- · Does not have a "flat" version (compared to sheet metal)
- Possible that there is a second part configuration that shows the mold shape.





#### **Design Benefits**

- Possible to Rapid Prototype (if system is in house)
- · Base Mold can be made from cheap materials
- · Complex Geometries
- · Large Size

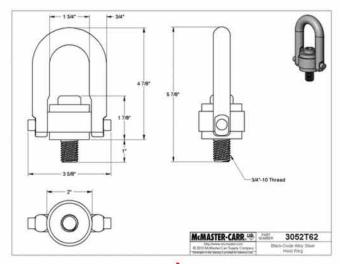
- · Non-structural parts
- · Additional hardware (inserts) needed for fastening
- · Post forming trimming / machining might be required



## Part & Assembly Identifiers: Stock Parts

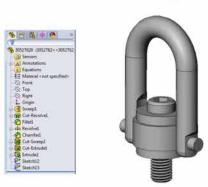
#### Part Identifiers - Stock Parts

- · MetaData has best clues
  - → Part Number is not associated with project name (i.e. UPI-\*\*\*\* is project file)
  - → "Stock" in Material or description
  - → Standard sizes might be in description (i.e. 1/4-20 bolt)
- · Feature List might be very sparse
  - → Imported parts will not have feature list at all, only a imported solid body
- · Could be single part or an assembly of parts
- · Sometimes parts can be computationally heavy or unusable
  - → Mechanical engineer would modify or remake the part so it is simpler
  - → Redraw single parts into movable assemblies





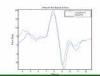




	Property Name	Тур	e	Value / Text Expression
L	Desc1	Text		Black-Oxide Alloy Steel
2	Desc2	Text		Hoist Ring
3	copywrite	Text	*	© 2010 McMaster-Carr Supply Company
4	<type a="" new="" property=""></type>			

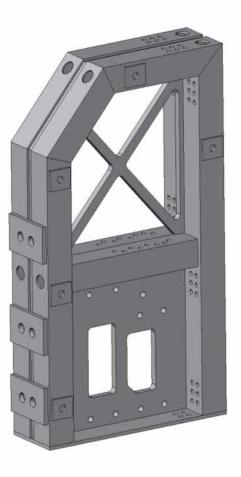


#### Part & Assembly Identifiers: Weldments



#### Assembly Identifiers – Weldments

- Possible to create complex geometries using multiple planar parts
  - → Used on the fame's tube structure multiple times
- Parts mated at hard edges
  - → Sometimes a gap is in assembly file to account for weld bead
  - → Sometimes there are alignment pins or jigs
- · Most common parts are waterjet components
  - → Waterjet components are located via slot and tabs
- · Common to see weld nuts or threaded inserts
  - → Weld nuts used with steel
  - Threaded inserts used with aluminum and softer metals to reinforce threaded holes
- · Can contain machined parts
  - → Easy to pick out compared to waterjet plates
  - → Example would be a machined shaft to maintain concentricity between multiple waterjet plates
- Could also be post-machined after welding
  - → This process could be repeated multiple times
- Possible to have high tolerance stack up
  - → Gap between slot and tabs is 0.2 mm (0.008")
  - → Metals flexes due to heat during welding
  - Holes for assembly onto other parts have conservative tolerances to account for slop



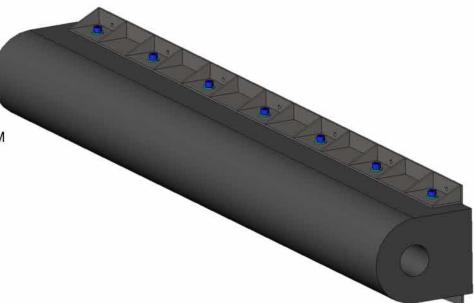


## Part & Assembly Identifiers: Assemblies



#### **Assembly Identifiers** – Fastened Assemblies

- Parts / Assemblies attached to each other through standard fastening methods
  - → Stock Fasteners Used
  - → Standard Sizes
- · Possible to have seals or spacers in between parts
  - → Rubber gaskets
    - Or any common deformable material
  - → Washers
- · Has at least one level deep of parts or sub-assemblies in BOM
- · Tolerances between parts are minimal
  - → Assembled faces are considered to be touching at zero gap
  - → Fastening holes should be concentric
- · Rare to have post machining on a fastened assembly



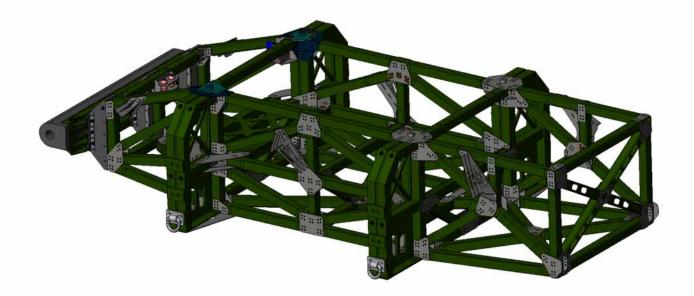


## **Application Example**



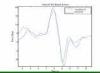
#### **UPI FRAME**

- · Show example parts / assemblies
- Explain why part / assembly types were chosen
- · Go from assembly level down to part level
- -Model Will be Available Shortly (~1 Week)
- -Native SW Files and Parasolids





## **Contact Information**



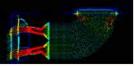
(b)(4); (b)(6)

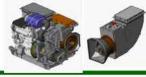
## National Robotics Engineering Center

(b)(4); (b)(6)

POC:







# **Experimental Vehicle (XV) Thermal Management**

30 Nov 2011

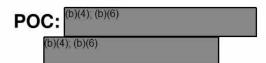


Carnegie Mellon University

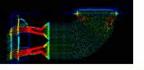
National Robotics Engineering Center

Ten 40<sup>th</sup> St.,

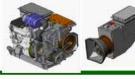
Pittsburgh, PA 15201



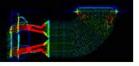




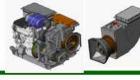
## **Forward**



- Vehicle/Thermal systems Overview
- Model Overview
- Simulink model
- Inputs
- · Kuli model
- Outputs
- Model details



## **Forward**



## Reference information – useful during setup and operation of model

Abbreviation	Meaning
AC	Air conditioner
ВРНХ	Bypass (counter flow) heat exchanger
CAC	Charge Air Cooler
DCDC	DC-DC Converter
EGW	Ethylene Glycol Water
hPa	Hectopascal (millibar)
HV	High Voltage
HX	Heat Exchanger
kph	kilometers per hour
kW	kilowatt
LF	Left front
LM	Left middle
LPM	Liters per minute
LR	Left rear
LV	Low Voltage
MV	Medium Voltage
PGW	Propylene Glycol Water
RF	Right front
RM	Right middle
RPM	Revolutions per minute
RR	Right rear
SA	Sub-ambient
SCFM	Standard cubic feet per minute
V	Volt
XV	Experimental Vehicle

Simulink Model:

C:\ECS\KULI\_80102\data\forMatlabWork\XV\_Full.mdl

Init Fcn callback:

C:\ECS\KULI 80102\data\forMatlabWork\HeatLoads.m

Init Fcn callback inputs:

C:\ECS\KULI\_80102\data\forMatlabWork\STEM\_Data\HighSpeed80kph\PAResults.csv

C:\ECS\KULI 80102\data\forMatlabWork\STEM Data\Dirt45kph\PAResults.csv

C:\ECS\KULI 80102\data\forMatlabWork\STEM Data\MaxGrade5kph\PAResults.csv

Kuli Model:

C:\ECS\KULI\_80102\data\CoolingSystems\XV\_Full.scs

Kuli Application:

C:\Program Files (x86)\ECS\KULI\_80102\Program\Kuli.exe

S-function:

C:\ECS\KULI\_80102\data\forMatlabWork\KULI\_server.m

COM File Location:

C:\ECS\KULI 80102\data\forMatlabWork\COM Definition XV Full.xls

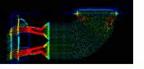
Results:

C:\ECS\KULI\_80102\data\Results\XV\_Full.scsPost

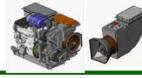
Matlab version:

R2009a, 32-bit



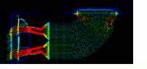


#### Overview - XV

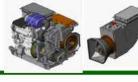


- Experimental Vehicle (XV) key requirements
  - → Mobility requirements steady state stressing cases (80 kph, flat, pavement; 45 kph, flat, dirt; 5 kph, 60% grade, pavement)
  - → Objective: Mobility requirements at 45 C ambient, full solar with ballistic grills
  - → Threshold: Full capability at 25 C without ballistic grills
- Developed, adjusted and validated thermal models then built XV
- XV Testing
  - → Component Testing: early and often, found and fixed problems early
  - → Dynamometer (Vehicle) Testing: high power, ambient conditions up to 45 C, temperature controlled chassis dynamometer = most thermally demanding mobility requirements; reached temps just shy of 45 C)
  - → Vehicle Testing: outdoor environment, temperatures reached 43 C



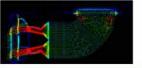


## XV Challenges



- High performance (vehicle, mission equipment)
- Rejecting heat
  - → Limited volume for air flow
  - → Ballistic grills
  - → High ambient temperature
  - $\rightarrow$  Dust
  - → Coolant flow limits
  - → Wide ranging inlet temp & flow rate
  - → Sub ambient necessary
  - → Pump, compressor and fan power management (design perspective)
- Thermal modeling complex thermal system matches model (each has four cooling loops)
- Thermal model uses Matlab/Simulink and Kuli



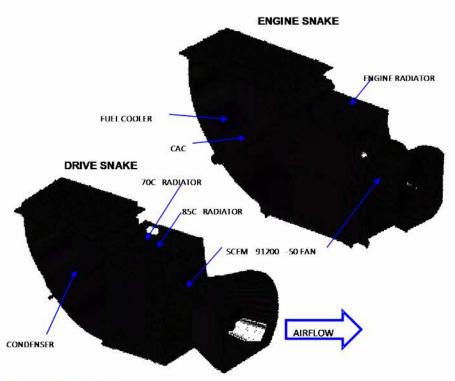


## **XV Thermal System Overview**



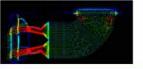
### Two air paths

- → Engine Snake (High temp): Engine & Charge Air Cooler (CAC)
- → Drive Snake (Low temp): Electronics, generators, motors



XV Engine and Drive Snake

AIRPATH 1 - Port Side (Drive Snake)		AIRPATH 2 - Starboard Side (Engine Snake)		
Heat Exchanger	Design Heat Rejection and Coolant Spec	Heat Exchanger	Design Heat Rejection and Coolant Spec	
A/C System Condenser (Batteries and Misc Electronics)	10 kW - 40 LPM @ 10 C (Chilled Coolant)	Single Pass Charge Air Cooler	60 C (Air)	
Single Pass Radiator (HV Electronics and Aux Motors/Generators)	12 kW - 225 LPM @ 70 C	Quad Pass Radiator (Engine and Brake Shunt Resistor)	120 kW - 180 LPM @ 95 C (Coolant)	
Dual Pass Radiator (Wheel Motors and Main Generator)	35 kW - 85 LPM @ 85 C			
Fan Airflow Estimate	Fan Power	Fan Airflow Estimate	Fan Power	
5100 SCFM @ 6100 RPM	10 kW Electrical @ 6100 RPM (Electric Motor Driven)	8600 SCFM @ 10,000 RPM	43 kW Mechanical @ 10,000 RPM (Electric Motor or Engine Drive; both via Belt)	



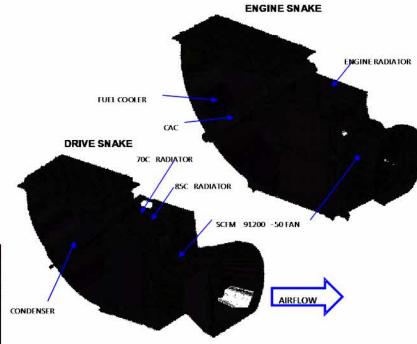
## **XV Thermal System Overview**



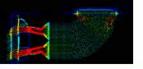
## Four liquid loops

- → Engine (high temp)
- →85 C (motors & generators)
- → 70 C (secondary generator, controlling electronics)
- → Sub-ambient (mission equipment)

DESCRIPT	ION OF COOLE	D COMPONENTS		
DRIVE SNAKE		ENGINER SNAKE		
SUB-AMBIENT LOOP	FUEL COOLER 60 c MAX FUEL TEMP			
10 kiwi MAX - 40 LPM WGW MAX at 10 C NOMINAL				
COMPONENT	QUANTITY	COMPONENT	QUANTITY	
LV Electronics Enclosure	1			
HV Electronics Enclosure	1			
Controller w/ Cold Plate	2	Engine Fuel (DF2 or JP8)	1	
Turret	1			
Battery Enclosure	2			
70C LOOP	CHARGE AIR COOLER			
12 kW MAX - 225 LPM EGW MAX at 70 C N	лах	60 C MAX AIR TEMP		
COMPONENT	QUANTITY	COMPONENT	QUANTITY	
Wheel Motor Controller	6		1	
Generator Controller	1			
Brake Chopper Shunt Controller	2			
350 V - 750 V Convertor	2	Engine Charge Air		
350 V Motor/Generator	1	Engine Charge An		
Generator Controller	1			
Drive Snake Fan Motor	1			
350 V to 12/28 V Convertor	3			
85 C LOOP	ENGINE LOOP			
35 kW MAX - 85 LPM EGW MAX at 85 C N	20 KW MAX (Engine Only) - 180 LPM EGW	MAX at 95 CA		
COMPONENT	QUANTITY	COMPONENT	QUANTITY	
Wheel Motor	6	Engine	1	
750 V Generator	1	Brake Shunt Resistor (40 kW Max Expected)	1	







## XV – Engine Loop



#### FUEL COOLER –

→ Maintained fuel temps in working range, no reduction in power on hot day

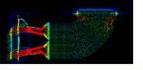
#### CHARGE AIR COOLER –

- → Parallel air flow w/ fuel cooler
- → Functioned as modeled

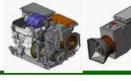
#### ENGINE LOOP

- → Maximum expected engine heat + 20% margin over test data used in model (fouling etc.)
- → Expected engine bay to be hot on cloudless summer day in hot region separate fan to vent engine bay a good approach
- → Maximum measured engine coolant flow rate used at max steady state load (mobility driven)
- → Prescribed shunt coolant inlet temperature maintained
- → Engine coolant inlet temperature predicted matched actual for conditions similar to model (cloudless hot summer day)
- → Engine never limited power (coolant = 105 C)





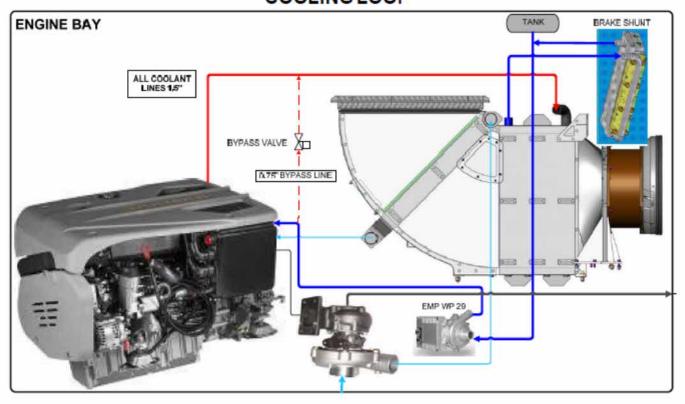
## XV – Engine Loop

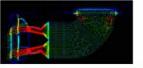


## Shunt cooling when engine off

- → Bypass valve and electric pump
- → Coolant flow lower than equipment spec
- → Coolant temp lower than equipment spec
- → Good performance

#### ENGINE COOLING LOOP



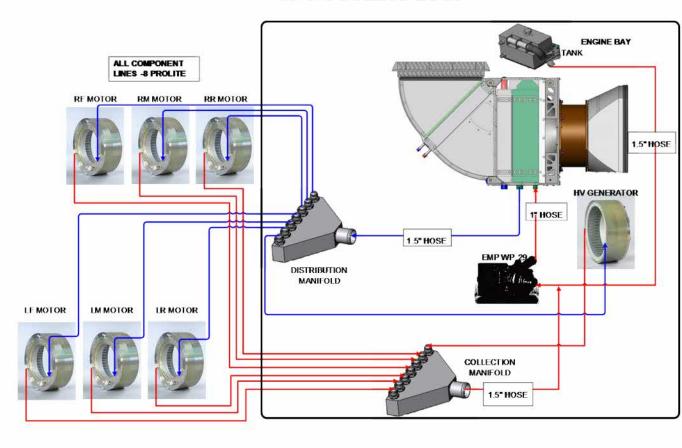


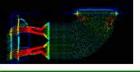
## XV - 85C Loop



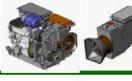
- Max load 80kph, 45C model & actual
- Flow rate has margin, pumps not at full speed
- Loop as thermal margin, other equipment could be added
- Simplest loop

#### 85 C COOLING LOOP

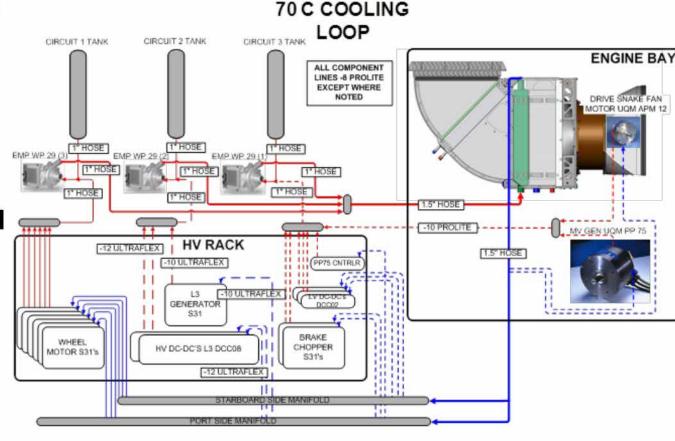


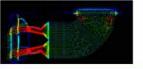


## XV - 70C Loop



- Max load 80kph,
   45C model & actual
- Flow rate slightly less than needed after quick disconnects installed (losses)
- Loop at limit (model & actual)
- 70C loop limited performance
- Slightly higher coolant flow rate – XV would have run at 45C, full solar





## XV – Sub-Ambient Loop

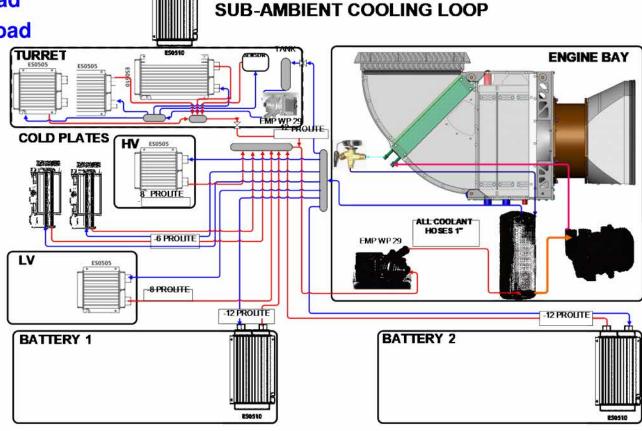


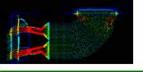
## Capacity

- → Max Eqpt & Vehicle Load
- → 45C ambient w/ Solar load

#### Air over heat xchg

- → Turret = all mission equipment
- $\rightarrow$  LV = LV PDU
- $\rightarrow$  HV = HV PDU
- → Battery Packs
- Cold plates = Ctrls
  - → Drive Snake Fan
  - → Compressor





## **Model Overview – Basic Operation**



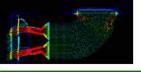
#### Model operations

- → Set stressing case in Heatloads.m
- → Run Simulink
- → Results can be viewed on Simulink Scopes, saved to Matlab workspace then plotted, or viewed in the Kuli post processing file
- → Detail instructions can be found in the ReadMe\_XV... document

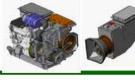
#### Modeling Assumptions

- → All components thermally soaked at ambient temperature (45C)
- → Vehicle starts and is driven at one speed, one engine setting (series hybrid)
- → Components temperature increase then operate at steady state





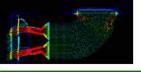
## **Model Overview – Basic Operation**



- Steady state thermal loads and power for three stressing cases (PAResults.csv)
  - $\rightarrow$  80 kph, flat, pavement (1)
  - $\rightarrow$  45 kph, flat, dirt (2)
  - $\rightarrow$  5 kph, 60% grade, pavement (3)
- Basic operations
  - → Set stressing case in Heatloads.m, save/
  - → Push Start in XV\_Full Simulink Model



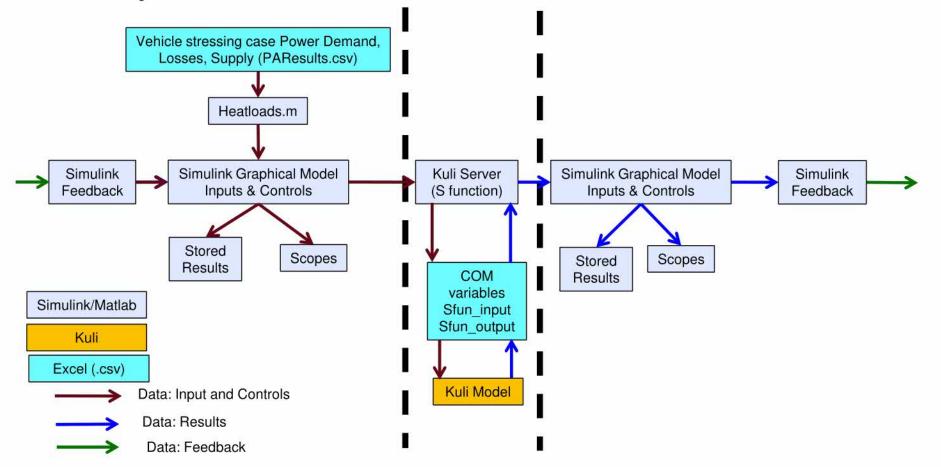
```
Editor - C:\ECS\KULI 80102\data\forMatlabWork\HeatLoads.m
      Text Go Cell Tools Debug Desktop Window Help
               りゅう 3 日・日本 4 4 4 6 2 - 日本 音音 音
           + + 11
      clear all
      % Initialization file for XV-Model
         Carnegie Mellon University
            **************************
           $$$3ET SIMULATION AND COMPONENT PARAMETERS$$$$$$$$$
      * SET STRESSING CASE
17
      % 1 = BOkph, pavement, 450
      % 2 = 45kph, dirt, 45C (+10% traction power added for turning)
19
      % 3 = 5kph, pavement, 60% grade ascent, 450
20 -
      StressingCase = 1;
```

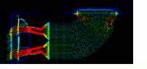


#### **Model Overview – Basic Structure**

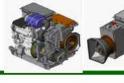


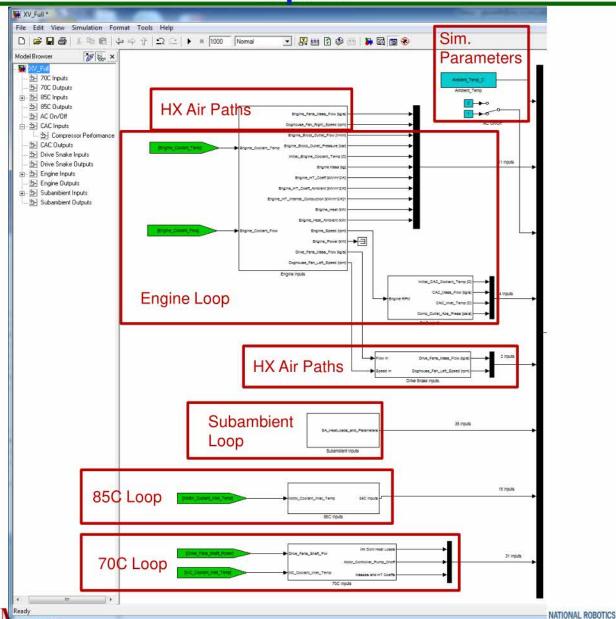
- Model used for all airside and liquid circuits for cooling system
- Thermal and power inputs loaded via Heatloads.m from PAResults.csv
- Other inputs hard coded in Heatloads.m



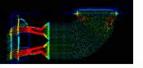


## XV Simulink Model – Inputs



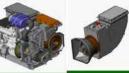


**ENGINEERING CENTER** 



## XV Simulink Model -**Inputs to KULI**

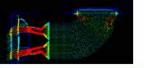




Key Engine Loop CAC Loop Fans SA 134a Loop SA EGW Loop 85C Loop 70C Loop

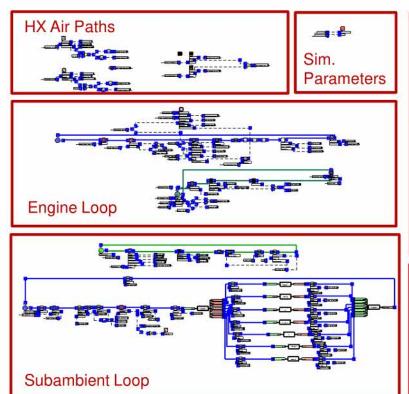
In for KULI			
Ambient_Temp_C	С		
Engine Fans Mass Flow	kg/s		
Doghouse_Fan_Right_Speed	1/min		
Engine_Block_Outlet_Flow	I/min		
Engine Block Outlet Pressure	bar		
Initial_Engine_Coolant_Temp	С		
Engine_Mass	kg		
Engine_HT_Coeff	kW/m^2/K		
Engine_HT_Coeff_Ambient	kW/m^2/K		
Engine_Internal_Conduction	W/m/K		
Engine_Heat	kW		
Engine_Heat_Ambient	kW		
AC Onoff	untransformed		
Initial_CAC_Coolant_Temp	C		
CAC_Mass_Flow	kg/s		
CAC Inlet Temp	C		
Comp_Outlet_Abs_Press	psi		
Drive Fans Mass Flow			
Doghouse_Fan_Left_Speed	kg/s 1/min		
PFC Length	-		
	mm 1/min		
AC_Comp_Speed	A COLUMN TO A COLU		
Battery1_Heat	kW		
Battery2 Heat	kW		
Battery1_Ambient_Heat Battery2_Ambient_Heat	kW		
Battery2_Ambient_Heat	kW		
HV_Box_Heat HV_Box_Ambient_Heat	kW		
	kW		
LV_Box_Heat	kW		
LV_Box_Ambient_Heat	kW		
Turret_Heat	kW		
Turret_Ambient_Heat	kW		
Cont1_Heat	kW		
Cont1_Ambient_Heat	kW		
Cont2_Heat	kW		
Cont2_Ambient_Heat	kW		
SA_Main_Line_Dia	mm		
Batt_Line_Dia_mm	mm		
HLV_Line_Dia_mm	mm		
Cont_Line_Dia_mm	mm		
SA_PGW_Temp_CMD	C		
Battery1_SCFM	ft^3/min		
Battery2_SCFM	ft^3/min		
HV Box SCFM	ft^3/min		
HV_Box_SCFM LV_Box_SCFM	ft^3/min		
Turret_SCFM	ft^3/min		
CA BOW Burn Oneff	1/min		

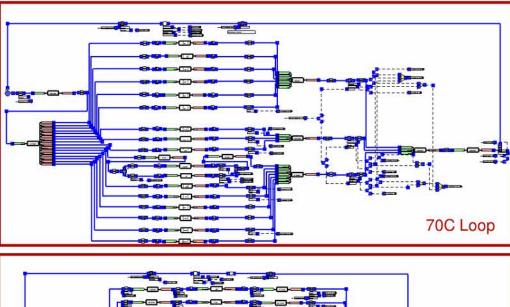
E-V-IVIII I	i
In for KULI	LAM
Motor_Heat_LF	kW
Motor_Heat_LM	kW
Motor_Heat_LR	kW
Motor_Heat_RF	kW
Motor Heat RM	kW
Motor_Heat_RR	kW
Generator1_Heat	kW
Motor_Pump_Onoff	1/min
Initial_Motor_Coolant_Temp	C
Motor_Mass	kg
Generator1_Mass	kg
Motor_HT_Coeff	kW/m^2/K
Generator1_HT_Coeff	kW/m^2/K
Mtr_Line_Dia_mm	mm
Gen_Line_Dia_mm	mm
Motor_Controller_Heat_LF	kW
Motor_Controller_Heat_LM	kW
Motor_Controller_Heat_LR	kW
Motor_Controller_Heat_RF	kW
Motor_Controller_Heat_RM	kW
Motor_Controller_Heat_RR	kW
Generator1_Controller_Heat	kW
Generator2_Heat	kW
Generator2_Controller_Heat	kW
DCDC1_1_Heat	kW
DCDC1_2_Heat	kW
LVDCDC_1_Heat	kW
	kW
LVDCDC_3_Heat	kW
Brake_Cont_1_Heat	kW
Brake Cont 2 Heat	kW
DriveFanMotor_MandC_Heat	kW
Motor Controller Pump Onoff	1/min
Initial_Controller_Coolant_Temp	
	kg
Generator1_Controller_Mass	kg
MV_Generator2_Mass	kg
MV_Generator2_Controller_Mas	
DCDC1_Mass	kg
LVDCDC_Mass	kg
Motor_Controller_HT_Coeff	kW/m^2/K
MV_Gen2_HT_Coeff	kW/m^2/K
MV_Gen2_Cont_HT_Coeff	kW/m^2/K
DCDC1_HT_Coeff	kW/m^2/K
LVDCDC_HT_Coeff	kW/m^2/K
Initial_Gen2_Coolant_Temp	С

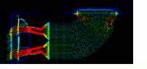


## XV KULI Model -**Coolant Loop Sections**

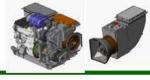


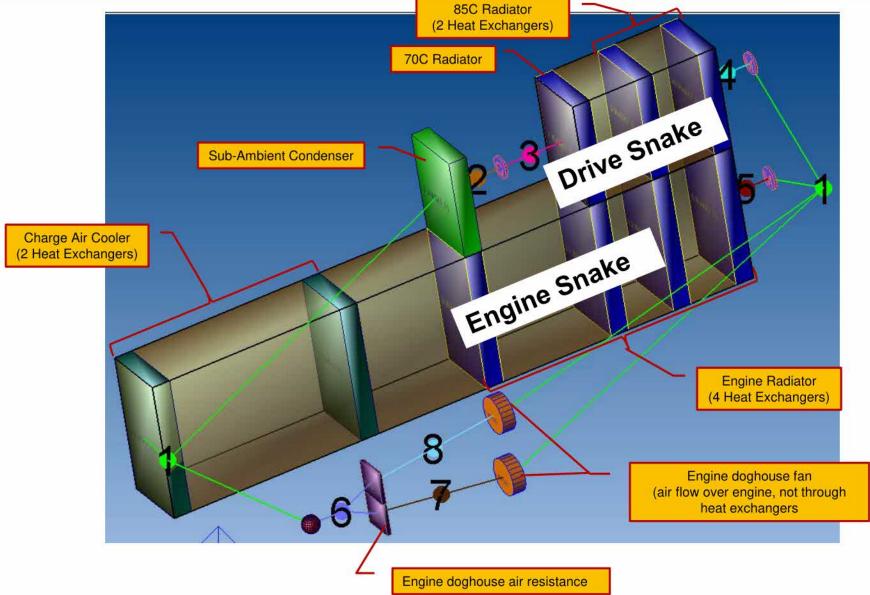


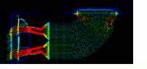




## XV KULI Model – Air Paths

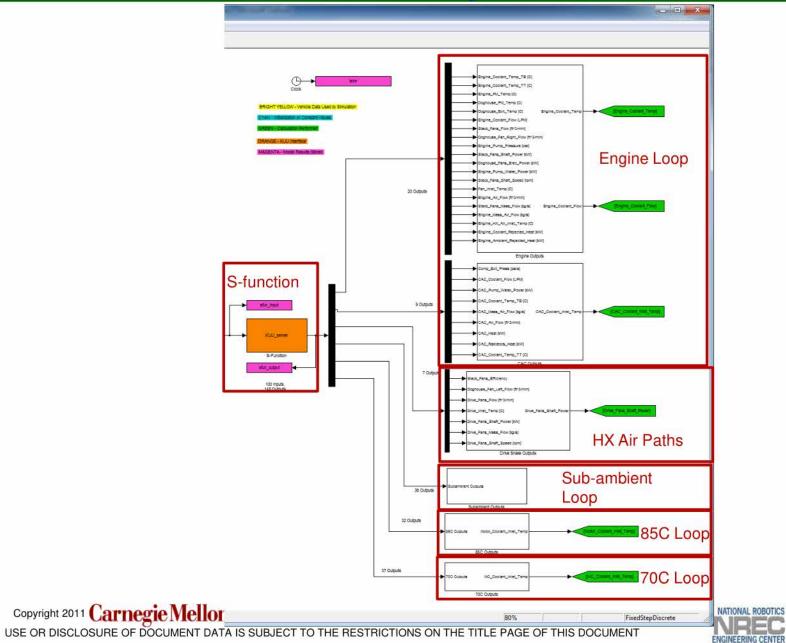


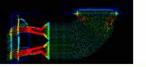




## XV Simulink Model -**Outputs**







Out of KULI

## XV Simulink Model – Outputs



Key
Engine Loop
CAC Loop
Fans
SA 134a Loop
SA EGW Loop
85C Loop
70C Loop

Out of KULI	
Engine_Coolant_Temp_TB	С
Engine Coolant Temp TT	С
Engine_PM_Temp	С
Doghouse_PM_Temp	c
Doghouse_Exit_Temp	С
Engine_Coolant_Flow	I/min
Stack_Fans_Flow	ft^3/min
Doghouse_Fan_Right_Flow	ft^3/min
Engine Pump Pressure	bar
Stack_Fans_Shaft_Power	kW
Doghouse Fans Elec Power	kW
Engine_Pump_Water_Power	kW
Stack Fans Shaft Speed	1/min
Fan_Inlet_Temp	C
Engine_Air_Flow	ft^3/min
Stack_Fans_Mass_Flow	kg/s
Engine_Mass_Air_Flow	kg/s
Engine_HX_Air_Inlet_Temp	C Rg/s
Engine_RX_All_Inlet_remp Engine_Coolant_Rejected_Heat	kW
Engine_Coolant_Rejected_Heat	kW
	J. Committee
Comp_Exit_Press	psi
CAC Coolant Flow	I/min
CAC_Pump_Water_Power	kW
CAC_Coolant_Temp_TB	C
CAC_Mass_Air_Flow	kg/s
CAC_Air_Flow	ft^3/min
CAC_Heat	kW
CAC_Radiators_Heat	kW
CAC Coolant Temp TT	С
Stack_Fans_Efficiency	untransformed
Doghouse_Fan_Left_Flow	ft^3/min
Drive_Fans_Flow	ft^3/min
Drive_Inlet_Temp	С
Drive_Fans_Shaft_Power	kW
Drive_Fans_Mass_Flow	kg/s
Drive_Fans_Shaft_Speed	1/min
SA_Cond_Heat	kW
AC_Balanced	untransformed
SA_Comp_Power	kW
SA_Cond_Temp	С
SA_Cond_Temp_Out	С
SA_Evap_Temp_Out	С
Comp_Pin	psi
Comp_Pout	psi
Comp_Mass_Flow	kg/s
SA Comp Power 2 Refrigerant	kW/

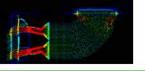
Out of KULI	
SA_PGW_Temp	С
SA_PGW_Temp_Target_Heat	kW
Battery1_Air_Temp_Out	C
Battery1_Air_Temp_In	C
Battery2_Air_Temp_Out	C
Battery2_Air_Temp_In	С
Battery2 Air Temp Out Battery2 Air Temp In HV Box Air Temp Out	C
HV_Box_Air_Temp_In	С
LV Box Air Temp Out	C
LV Box Air Temp In	С
Turret_Air_Temp_Out	С
Turret_Air_Temp_In	C
Cont1_Temp	С
Cont1_Temp Cont2_Temp	C
SA_PGW_GPM	US GPM
Battery1_GPM	US GPM
Battery2_GPM	US GPM
HV_Box_GPM	US GPM
LV_Box_GPM	US GPM
Turret GPM	US GPM
Cont1 GPM	US GPM
Cont2_GPM	US GPM
BPHX_Temp_In	C
BPHX_dP_Act	psi
BPHX_Temp_Out	C
M_Coolant_Temp_TT	С
M Coolant Flow	I/min
M Air Flow	ft^3/min
M_Coolant_Heat	kW
M_Coolant_Temp_TB	С
Motor_Pump_Water_Power	kW
LF_Coolant_Flow	US GPM
LM_Coolant_Flow	US GPM
LR Coolant Flow	US GPM
RF Coolant Flow	US GPM
RM Coolant Flow	US GPM
RR Coolant Flow	US GPM
G1_Coolant_Flow	US GPM
LF_Coolant_Temp	C
LM_Coolant_Temp	C
	C
LR Coolant Temp	
RF_Coolant_Temp	С
RM_Coolant_Temp RR_Coolant_Temp	C
	163
G1_Coolant_Temp  M_Coolant_Exit_Temp	C

Out of KULI  LF Motor Temp  C  LM Motor Temp  C  RF Motor Temp  C  RM Mass Air Flow  Motor Pump Flow  Motor Pump Flow  Motor Pump dP  Motor Pump dP  Motor Temp  C  MC Coolant Flow  MC Rad Inlet Air Temp  C  MC Coolant Heat  MC Air Flow  MC Air Flow  MC Air Flow  MC Coolant Temp TB  C  Controller Pump Water Power  RM COolant Flow  G2 Coolant Flow  MC Coolant Flow  MC Coolant Temp  C  MC Coolant Temp  C  C  RC Coolant Temp  C  RC		
LM Motor Temp  C RR Motor Temp  C G1 Temp  C M Mass Air Flow  M Coolant Inlet Temp  C Motor Pump Flow  Motor Pump dP  MC Coolant Temp TT  C MC Coolant Flow  MC Air Flow  MC Air Flow  MC Air Flow  MC Coolant Temp TB  C Controller Pump Water Power  MC Coolant Flow  C Controller Pump C C  MC Coolant Flow  C Controller Pump C C  MC Coolant Flow  C Controller Pump C C  MC Coolant Flow  C C C C C C C C C C C C C C C C C C C		
LM Motor Temp  C RR Motor Temp  C G1 Temp  C M Mass Air Flow  M Coolant Inlet Temp  C Motor Pump Flow  Motor Pump dP  MC Coolant Temp TT  C MC Coolant Flow  MC Air Flow  MC Air Flow  MC Air Flow  MC Coolant Temp TB  C Controller Pump Water Power  MC Coolant Flow  C Controller Pump C C  MC Coolant Flow  C Controller Pump C C  MC Coolant Flow  C Controller Pump C C  MC Coolant Flow  C C C C C C C C C C C C C C C C C C C	LF_Motor_Temp	С
RF Motor Temp  RM Motor Temp  C RM Motor Temp  C RT Motor Temp  C M Mass Air Flow  M Coolant Inlet Temp  C Motor Pump Flow  Motor Pump Plow  Motor Pump TT  C  Motor Coolant Temp TT  C  Motor Coolant Flow  Motor Itmin  Motor Rad Inlet Air Temp  C  Motor Coolant Flow  Motor Itemp  C  Motor Coolant Flow  Imin  G2 Coolant Flow  Motor Temp  C  Motor Temp  Motor Temp  Notor Temp  Notor Temp  Motor Temp  Notor Temp  Motor Temp  Notor Temp  Motor Temp  Notor Temp	LM_Motor_Temp	C
RF Motor Temp  RM Motor Temp  C RM Motor Temp  C RT Motor Temp  C M Mass Air Flow  M Coolant Inlet Temp  C Motor Pump Flow  Motor Pump Plow  Motor Pump TT  C  Motor Coolant Temp TT  C  Motor Coolant Flow  Motor Itmin  Motor Rad Inlet Air Temp  C  Motor Coolant Flow  Motor Itemp  C  Motor Coolant Flow  Imin  G2 Coolant Flow  Motor Temp  C  Motor Temp  Motor Temp  Notor Temp  Notor Temp  Motor Temp  Notor Temp  Motor Temp  Notor Temp  Motor Temp  Notor Temp	LR_Motor_Temp	
RM_Motor_Temp	RF Motor Temp	С
RR Motor Temp C G1 Temp C M Mass Air Flow kg/s M Coolant Inlet Temp C Motor Pump Flow US GPM Motor Pump GP psi MC Coolant Temp TT C MC Coolant Flow I/min MC Rad Inlet Air Temp C MC Coolant Heat kW MC Air Flow ft^3/min MC Coolant Temp TB C Controller Pump Water Power kW G2 Coolant Flow I/min G2 Coot Coolant Flow I/min G2 Coot Temp C MC Coolant Exit Temp C MC Coolant Temp C MC Coolant Flow I/min G2 Cont Temp C MC Coolant Flow I/min G2 Cont Temp C MC Coolant Flow I/min G2 Cont Temp C MC Coolant Flow I/min G2 Cootant Temp C MC Coolant Exit Temp C G3 Temp C MC Coolant Temp C MC Coolant Exit Temp C C RR Cont Temp C RR Cont Temp C G1 Cont Temp C G2 Coolant Flow I/min C C G2 Coolant Flow I/min C C G3 Temp C G4 Coolant Flow I/min C C G5 Coolant Flow I/min C C COOLANT Emp C C C COOLANT Emp C C C C C C C C C C C C C C C C C C C	RM Motor Temp	С
G1_Temp		С
M_Mass_Air_Flow	G1 Temp	С
M_Coolant_Inlet_Temp		
Motor_Pump_dP		
Motor_Pump_dP		US GPM
MC_Coolant_Temp_TT		
MC_Coolant_Flow   I/min   MC_Rad_Inlet_Air_Temp   C   MC_Coolant_Heat   kW   MC_Air_Flow   ft^3/min   MC_Coolant_Temp_TB   C   Controller_Pump_Water_Power   kW   G2_Coolant_Flow   I/min   G2_Cont_Coolant_Flow   I/min   G2_Coolant_Temp   C   MC_Coolant_Exit_Temp   C   CG2_Temp   C   LF_Cont_Temp   C   LF_Cont_Temp   C   LR_Cont_Temp   C   RF_Cont_Temp   C   RR_Cont_Temp   C   RR_Cont_Temp   C   RR_Cont_Temp   C   G1_Cont_Temp   C   G2_Cont_Temp   C   RR_Cont_Temp   C   G2_Cont_Temp   C   G3_Coolant_Inlet_Temp   C   G4_Coolant_Inlet_Temp   C   G2_Coolant_Inlet_Temp   C   G2_Coolant_Inlet_Temp   C   G3_Coolant_Inlet_Temp   C   G4_Coolant_Inlet_Temp   C   CDCDC1_Coolant_Flow   I/min   LVDCDC_Coolant_Flow   I/min   RR_Controller_Coolant_Flow   I/min   RR_Controller_Coolant_Flow   I/min   RR_Controller_Coolant_Flow   I/min   Controller_Pump_1_Telow   US_GPM   Controller_Pump_2_Flow   US_GPM   Controller_Pump_3_Flow		
MC_Rad_Inlet_Air_Temp		I/min
MC_Coolant_Heat kW  MC_Air_Flow ft^3/min  MC_Coolant_Temp_TB C  Controller_Pump_Water_Power kW  G2_Coolant_Flow l/min  G2_Cont_Coolant_Flow l/min  G2_Coolant_Temp C  MC_Coolant_Exit_Temp C  G2_Temp C  LF_Cont_Temp C  LM_Cont_Temp C  LR_Cont_Temp C  RR_Cont_Temp C  RR_Cont_Temp C  G1_Cont_Temp C  G2_Cont_Temp C  RR_Cont_Temp C  G2_Cont_Temp C  G2_Cont_Temp C  G2_Coolant_Exit_Temp C  RR_Cont_Temp C  RR_Cont_Temp C  G2_Coolant_Exit_Temp C  G2_Cont_Temp C  RR_Cont_Temp C  G2_Coolant_Flow kg/s  MC_Coolant_Inlet_Temp C  G2_Coolant_Inlet_Temp C  G3_Coolant_Inlet_Temp C  G4_Coolant_Inlet_Temp C  G4_Coolant_Inlet_Temp C  G4_Coolant_Inlet_Temp C  G4_Coolant_Inlet_Temp C  G4_Coolant_Inlet_Temp C  G		
MC Air Flow ft*3/min  MC Coolant Temp TB C  Controller Pump Water Power kW  G2 Coolant Flow I/min  G2 Coolant Flow I/min  G2 Coolant Temp C  MC Coolant Exit Temp C  G2 Temp C  LF Cont Temp C  LR Cont Temp C  RR Cont Temp C  RR Cont Temp C  RR Cont Temp C  G1 Cont Temp C  G2 Coolant Flow C  RR Cont Temp C  RR Cont Temp C  G2 Coolant Flow C  RR Cont Temp C  G3 Coolant Flow C  C C  RR Cont Temp C  RR Cont Temp C  G2 Coolant Flow C  MC Mass Air Flow Kg/s  MC Coolant Inlet Temp C  G2 Coolant Inlet Temp C  G2 Coolant Inlet Temp C  CODCD 1 Coolant Flow I/min  LVDCDC 1 Coolant Flow I/min  RR Controller Coolant Flow I/min  RR Controller Coolant Flow I/min  Brake Cont 1 Coolant Flow US GPM  Controller Pump 1 Flow US GPM  Controller Pump 2 Flow US GPM  Controller Pump 3 Flow US GPM  Controller Pump 3 Flow US GPM  Controller Pump 3 Flow US GPM  Controller Pump 5 Flow US GPM		
MC_Coolant_Temp_TB		
Controller_Pump_Water_Power kW  G2_Coolant_Flow		
G2 Coolant Flow   I/min   G2 Cont Coolant Flow   I/min   G2 Coolant Temp   C   MC_Coolant_Exit_Temp   C   G2_Temp   C   LF_Cont_Temp   C   LF_Cont_Temp   C   LR_Cont_Temp   C   LR_Cont_Temp   C   RF_Cont_Temp   C   RR_Cont_Temp   C   RR_Cont_Temp   C   RR_Cont_Temp   C   G1_Cont_Temp   C   G2_Cont_Temp   C   G2_Cont_Temp   C   G2_Coolant_Inlet_Temp   C   G2_Coolant_Inlet_Temp   C   CC_COOLANT_Inlet_Temp   C   CC_COOLANT_Inlet_Temp   C   DCDC1_1_Coolant_Flow   I/min   LVDCDC 1_Coolant_Flow   I/min   RR_Controller_Coolant_Flow   I/min   RR_Controller_Coolant_Flow   I/min   RR_Controller_Coolant_Flow   I/min   Controller_Pump 1_Flow   US_GPM   Controller_Pump 2_Flow   US_GPM   Controller_Pump 3_Flow   US_GPM   Controller_Pump 5_Flow   US_GPM   Con		
G2_Cont_Coolant_Flow		
G2 Coolant_Temp C  MC_Coolant_Exit_Temp C  G2_Temp C  LF_Cont_Temp C  LM_Cont_Temp C  LR_Cont_Temp C  LR_Cont_Temp C  RR_Cont_Temp C  RR_Cont_Temp C  RR_Cont_Temp C  RR_Cont_Temp C  RR_Cont_Temp C  G1_Cont_Temp C  G2_Cont_Temp C  MC_Mass_Air_Flow kg/s  MC_Coolant_Inlet_Temp C  G2_Coolant_Inlet_Temp C  DCDC1_1_Coolant_Flow I/min  LVDCDC 1_Coolant_Flow I/min  RR_Controller_Coolant_Flow US GPM  Controller_Pump_1_dP psi  Controller_Pump_2_dP psi  Controller_Pump_3_Flow US GPM		
MC_Coolant_Exit_Temp         C           G2_Temp         C           LF_Cont_Temp         C           LM_Cont_Temp         C           LR_Cont_Temp         C           RF_Cont_Temp         C           RR_Cont_Temp         C           RR_Cont_Temp         C           G1_Cont_Temp         C           G2_Cont_Temp         C           MC_Mass_Air_Flow         kg/s           MC_Coolant_Inlet_Temp         C           G2_Coolant_Inlet_Temp         C           G2_Coolant_Inlet_Temp         C           DCDC1_1_Coolant_Flow         I/min           LVDCDC 1_Coolant_Flow         I/min           G1_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           RR_Controller_Pump_1_Flow         US GPM           Controller_Pump_2_Flow         US GPM           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_Flow         US GPM           Controller_Pump_5_Flow         US GPM		
G2 Temp		
LF_Cont_Temp         C           LM_Cont_Temp         C           LR_Cont_Temp         C           RF_Cont_Temp         C           RR_Cont_Temp         C           RR_Cont_Temp         C           G1_Cont_Temp         C           G2_Cont_Temp         C           MC_Mass_Air_Flow         kg/s           MC_Coolant_Inlet_Temp         C           G2_Coolant_Inlet_Temp         C           DCDC1_1_Coolant_Flow         I/min           LVDCDC_1_Coolant_Flow         I/min           G1_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           Brake_Cont_1_Coolant_Flow         I/min           Controller_Pump_1_Flow         US GPM           Controller_Pump_1_AP         psi           Controller_Pump_2_Blow         US GPM           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_Flow         US GPM           Controller_Pump_5_Flow         US GPM		
LM_Cont_Temp         C           LR_Cont_Temp         C           RF_Cont_Temp         C           RM_Cont_Temp         C           RR_Cont_Temp         C           G1_Cont_Temp         C           G2_Cont_Temp         C           MC_Mass_Air_Flow         kg/s           MC_Coolant_Inlet_Temp         C           G2_Coolant_Inlet_Temp         C           G2_Coolant_Inlet_Temp         C           DCDC1_1_Coolant_Flow         I/min           LVDCDC_1_Coolant_Flow         I/min           G1_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           Controller_Pump 1_Flow         US GPM           Controller_Pump 1_Flow         US GPM           Controller_Pump 2_Flow         US GPM           Controller_Pump 3_Flow         US GPM           Controller_Pump 3_Flow         US GPM           Controller_Pumps_Flow         US GPM		
LR_Cont_Temp C RF_Cont_Temp C RM_Cont_Temp C RR_Cont_Temp C RR_Cont_Temp C G1 Cont_Temp C G2 Cont_Temp C MC_Mass_Air_Flow kg/s MC_Coolant_Inlet_Temp C G2 Coolant_Inlet_Temp C G2 Coolant_Inlet_Temp C DCDC1_1_Coolant_Flow I/min LVDCDC_1_Coolant_Flow I/min G1_Controller_Coolant_Flow I/min RR_Controller_Coolant_Flow I/min UNDICUTED COOLANT_Flow I/min RR_Controller_Poolant_Flow I/min Controller_Poolant_Flow I/min Controller_Pump_1_Flow US_GPM Controller_Pump_2_Flow US_GPM Controller_Pump_2_Depsi Controller_Pump_3_Flow US_GPM Controller_Pump_3_Flow US_GPM Controller_Pump_3_Depsi Controller_Pump_3_Flow US_GPM		
RF_Cont_Temp         C           RM_Cont_Temp         C           RR_Cont_Temp         C           G1_Cont_Temp         C           G2_Cont_Temp         C           MC_Mass_Air_Flow         kg/s           MC_Coolant_Inlet_Temp         C           G2_Coolant_Inlet_Temp         C           G2_Coolant_Inlet_Temp         C           DCDC1_1_Coolant_Flow         I/min           LVDCDC_1_Coolant_Flow         I/min           G1_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           Controller_Pump 1_Flow         US GPM           Controller_Pump 1_Flow         US GPM           Controller_Pump 2_Flow         US GPM           Controller_Pump 3_Flow         US GPM           Controller_Pump 3_Flow         US GPM           Controller_Pump 5_Flow         US GPM		C
RM_Cont_Temp         C           RR_Cont_Temp         C           G1_Cont_Temp         C           G2_Cont_Temp         C           MC_Mass_Air_Flow         kg/s           MC_Coolant_Inlet_Temp         C           G2_Coolant_Inlet_Temp         C           DCDC1_1_Coolant_Flow         I/min           LVDCDC_1_Coolant_Flow         I/min           G1_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           Controller_Pump 1_Flow         US GPM           Controller_Pump 1_Flow         US GPM           Controller_Pump 2_Flow         US GPM           Controller_Pump 3_Flow         US GPM           Controller_Pump 3_Flow         US GPM           Controller_Pump 3_Flow         US GPM           Controller_Pump 5_Flow         US GPM		
RR Cont Temp         C           G1 Cont Temp         C           G2 Cont Temp         C           MC Mass Air Flow         kg/s           MC Coolant Inlet Temp         C           G2 Coolant Inlet Temp         C           DCDC1_1 Coolant Flow         I/min           LVDCDC 1 Coolant Flow         I/min           RR Controller Coolant Flow         I/min           RR Controller Coolant Flow         I/min           Brake Cont_1 Coolant Flow         I/min           Controller Pump 1 Flow         US GPM           Controller Pump 2 Flow         US GPM           Controller Pump 2 Flow         US GPM           Controller Pump 3 Flow         US GPM           Controller Pump 3 Flow         US GPM           Controller Pump 3 Flow         US GPM           Controller Pump 5 Flow         US GPM		C
G1_Cont_Temp		
G2 Cont Temp C  MC Mass Air Flow kg/s  MC Coolant Inlet Temp C  G2 Coolant Inlet Temp C  DCDC1_1 Coolant Flow I/min  LVDCDC 1 Coolant Flow I/min  G1_Controller_Coolant Flow I/min  RR_Controller_Coolant Flow I/min  Brake_Cont_1 Coolant Flow I/min  Controller_Pump_1 Flow US GPM  Controller_Pump_2 Flow US GPM  Controller_Pump_3 Flow US GPM  Controller_Pump_5 Flow US GPM		
MC_Mass_Air_Flow kg/s  MC_Coolant_Inlet_Temp C  G2_Coolant_Inlet_Temp C  DCDC1_1_Coolant_Flow I/min  LVDCDC_1_Coolant_Flow I/min  G1_Controller_Coolant_Flow I/min  RR_Controller_Coolant_Flow I/min  Brake_Cont_1_Coolant_Flow I/min  Controller_Pump_1_Flow US_GPM  Controller_Pump_1_dP psi  Controller_Pump_2_dP psi  Controller_Pump_3_Flow US_GPM	1	
MC_Coolant_Inlet_Temp         C           G2_Coolant_Inlet_Temp         C           DCDC1_1_Coolant_Flow         I/min           LVDCDC_1_Coolant_Flow         I/min           G1_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           Brake_Cont_1_Coolant_Flow         I/min           Controller_Pump_1_Flow         US GPM           Controller_Pump_1_dP         psi           Controller_Pump_2_Flow         US GPM           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_GP         psi           Controller_Pump_5_Flow         US GPM		100000000000000000000000000000000000000
G2_Coolant_Inlet_Temp         C           DCDC1_1_Coolant_Flow         I/min           LVDCDC_1_Coolant_Flow         I/min           G1_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           Brake_Cont_1_Coolant_Flow         I/min           Controller_Pump_1_Flow         US GPM           Controller_Pump_1_dP         psi           Controller_Pump_2_Flow         US GPM           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_dP         psi           Controller_Pump_5_Flow         US GPM		
DCDC1 1 Coolant Flow I/min  LVDCDC 1 Coolant Flow I/min  G1_Controller_Coolant Flow I/min  RR_Controller_Coolant Flow I/min  Brake_Cont_1 Coolant Flow I/min  Controller_Pump_1 Flow US GPM  Controller_Pump_1 dP psi  Controller_Pump_2 Flow US GPM  Controller_Pump_3 Flow US GPM  Controller_Pump_3 Flow US GPM  Controller_Pump_3 Flow US GPM  Controller_Pump_3 Flow US GPM  Controller_Pump_5 Flow US GPM  Controller_Pump_5 Flow US GPM  Controller_Pump_5 Flow US GPM  Controller_Pump_5 Flow US GPM		
LVDCDC_1_Coolant_Flow         I/min           G1_Controller_Coolant_Flow         I/min           RR_Controller_Coolant_Flow         I/min           Brake_Cont_1_Coolant_Flow         I/min           Controller_Pump_1_Flow         US GPM           Controller_Pump_1_dP         psi           Controller_Pump_2_Flow         US GPM           Controller_Pump_2_dP         psi           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_Flow         US GPM           Controller_Pump_5_Flow         US GPM		
G1_Controller_Coolant_Flow		
RR_Controller_Coolant_Flow         I/min           Brake_Cont_1_Coolant_Flow         I/min           Controller_Pump_1_Flow         US GPM           Controller_Pump_1_dP         psi           Controller_Pump_2_Flow         US GPM           Controller_Pump_2_dP         psi           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_dP         psi           Controller_Pump_3_dP         psi           Controller_Pumps_Flow         US GPM		
Brake_Cont_1_Coolant_Flow         I/min           Controller_Pump_1_Flow         US GPM           Controller_Pump_1_dP         psi           Controller_Pump_2_Flow         US GPM           Controller_Pump_2_dP         psi           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_dP         psi           Controller_Pump_5_Flow         US GPM		
Controller Pump 1 Flow         US GPM           Controller Pump 1 dP         psi           Controller Pump 2 Flow         US GPM           Controller Pump 2 dP         psi           Controller Pump 3 Flow         US GPM           Controller Pump 3 dP         psi           Controller Pump 5 Flow         US GPM		
Controller_Pump_1_dP         psi           Controller_Pump_2_Flow         US GPM           Controller_Pump_2_dP         psi           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_dP         psi           Controller_Pumps_Flow         US GPM		
Controller Pump 2 Flow         US GPM           Controller Pump 2 dP         psi           Controller Pump 3 Flow         US GPM           Controller Pump 3 dP         psi           Controller Pumps Flow         US GPM		
Controller_Pump_2_dP         psi           Controller_Pump_3_Flow         US GPM           Controller_Pump_3_dP         psi           Controller_Pumps_Flow         US GPM		
Controller_Pump_3_Flow         US GPM           Controller_Pump_3_dP         psi           Controller_Pumps_Flow         US GPM		
Controller_Pump_3_dP psi Controller_Pumps_Flow US GPM		
Controller_Pumps_Flow US GPM		The state of the s
DriveFanMotor_Coolant_Flow  I/min		
	DriveFanMotor_Coolant_Flow	I/min

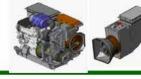
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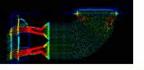


## XV KULI Model Overview – Simulation Parameters and Cases

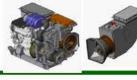


- Ambient temperature = 45C
- Ambient air pressure = 1013hPa
- Simulation time step = 1 sec
- Simulation run time = 1000 sec
- Other heat loads can be developed
  - → Data saved using the same PAResults file structure approach
  - → PAResults can be added to Heatloads.m
  - → Run Simulink

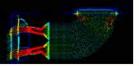


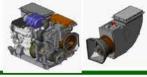


#### Conclusion

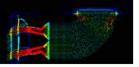


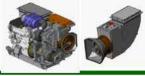
- Steady state thermal loads and power for three stressing cases (PAResults.csv) included
  - → 80 kph, flat, pavement (1)
  - $\rightarrow$  45 kph, flat, dirt (2)
  - → 5 kph, 60% grade, pavement (3)
- Simulink/Matlab output
  - → Additional scopes can be added to monitor variables
  - → Other controls can be added monitor temperatures and control compressor, pump, and fan flow rates
- The following slides are present the details of the thermal model.
   They can be used to develop a thermal model in a software package other than Kuli.



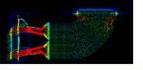


# Engine Snake Details





## **Engine EGW Loop**

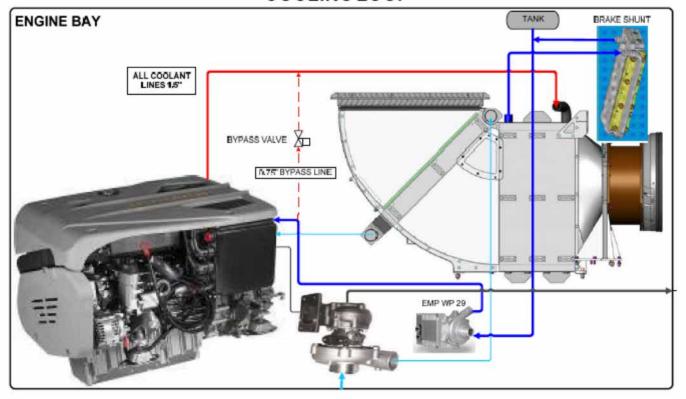


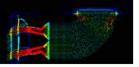
#### XV – Engine Loop



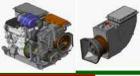
- CAC and EGW heat exchangers in Engine Snake
- Shunt cooling when engine off Bypass valve and electric pump used in lieu of engine water pump

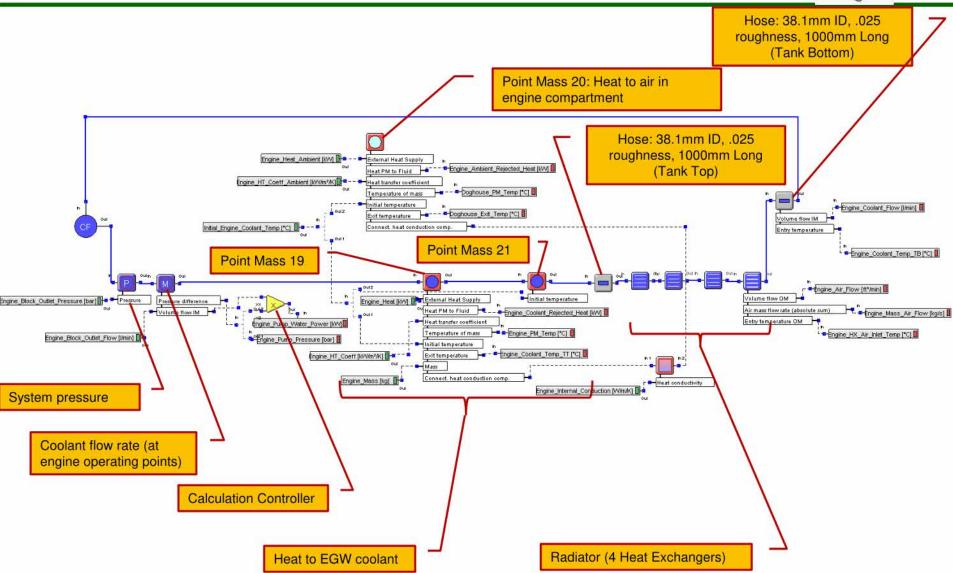
#### ENGINE COOLING LOOP

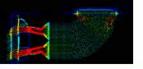




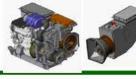
#### Kuli Engine EGW Loop

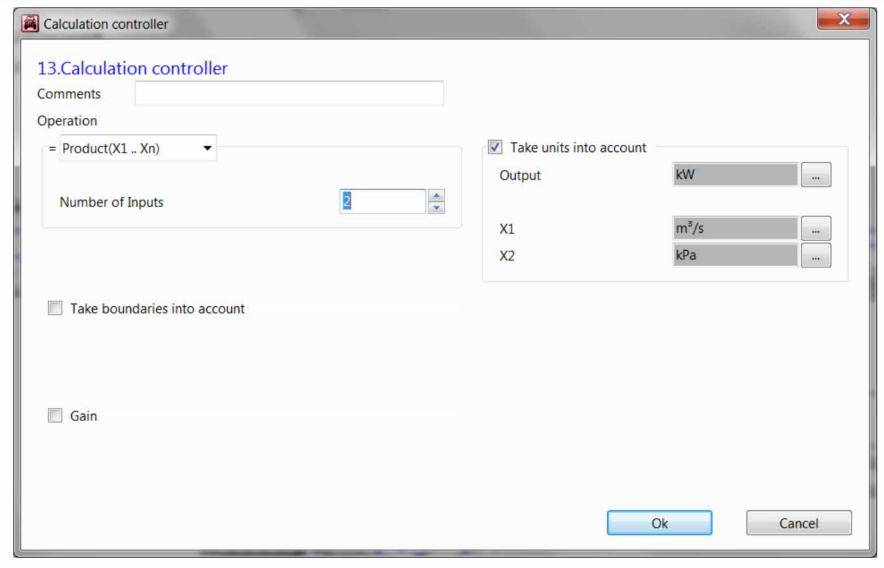


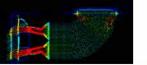




#### 13. Calculation controller

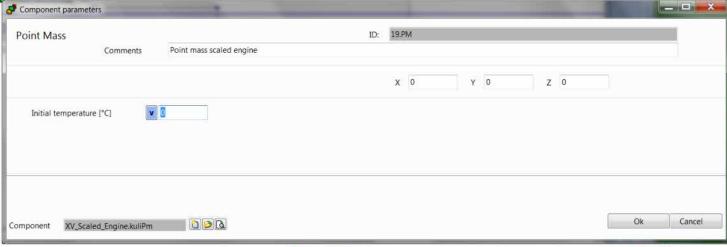


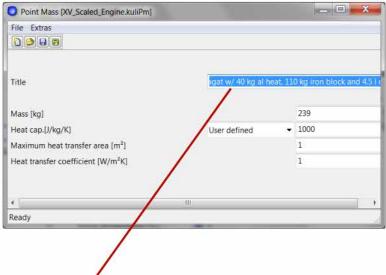




#### 19. Point mass scaled engine





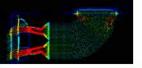


Scaled Engine - thermal mass is aggregate w/ 40 kg al heat, 110 kg iron block and 4.5 l oil

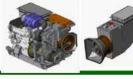
XV\_Scaled\_Engine.kuliPm

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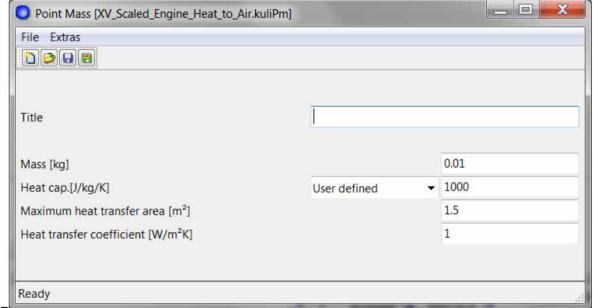




#### **20.Point Mass**

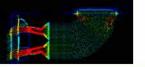




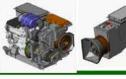


XV\_Scaled\_Engine\_Heat\_to\_Air.kuliPm





## 21.Point mass engine HX mass

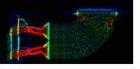




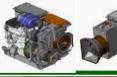
File Extras			
Title	Engine Radiator		
Mass [kg]			17.84
Heat cap.[J/kg/K]	Aluminium	•	837
Maximum heat transfer area [m²]			1
Heat transfer coefficient [W/m²K]			1
• [	"		
Ready			

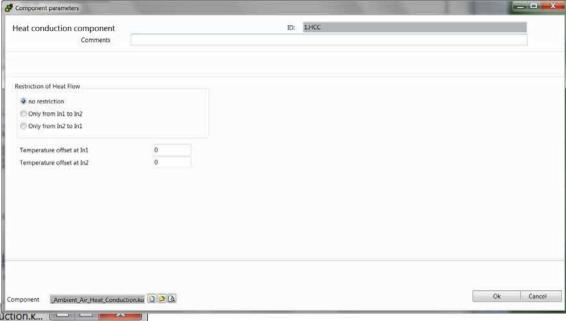
XV\_Engine\_HX.kuliPm

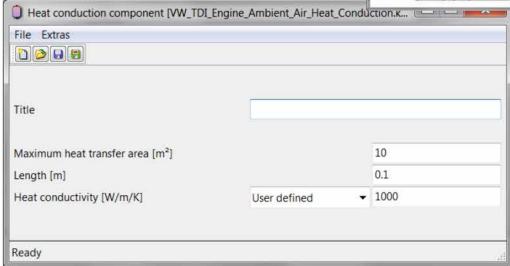




### 1.Heat conduction component

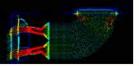


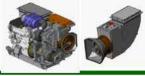




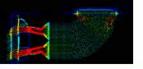
VW\_TDI\_Engine\_Ambient\_Air\_Heat\_Conduction.kuliDatHeat.kuliHcc



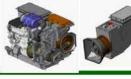


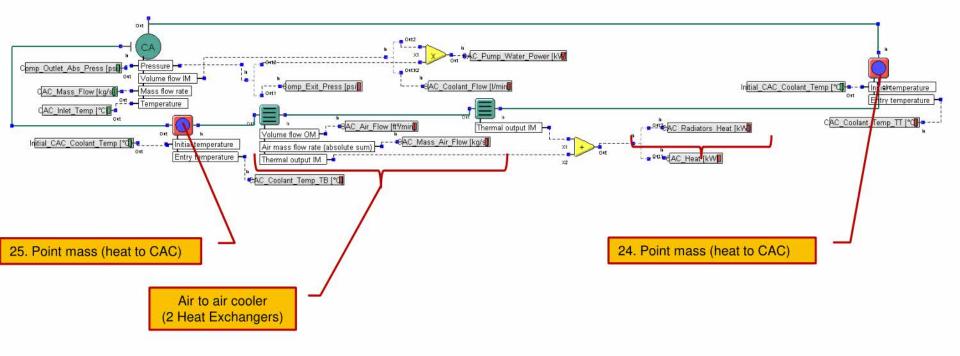


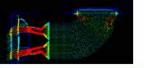
# Engine Charge Air Cooler Loop



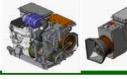
### Kuli Engine Charge Air Cooler Loop

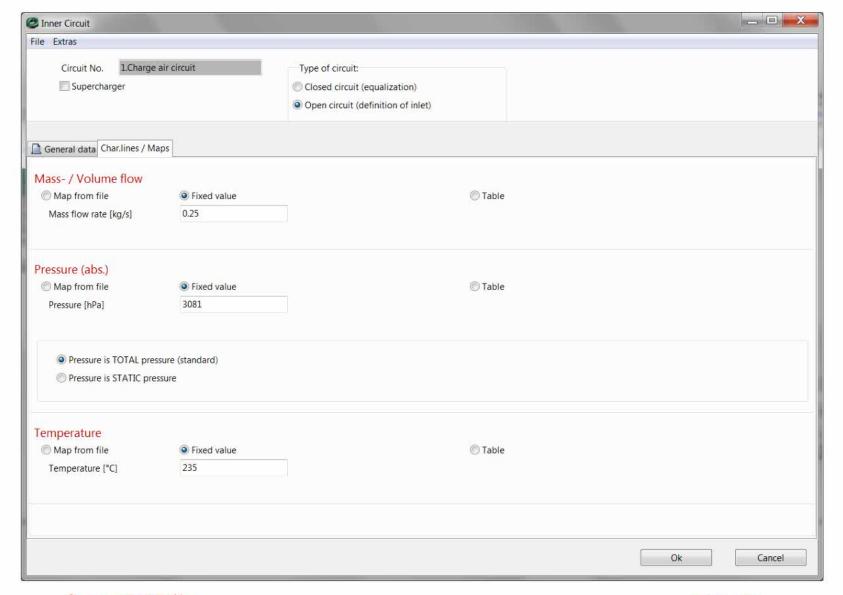


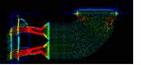




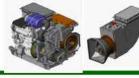
## Charge Air Circuit: Component parameters

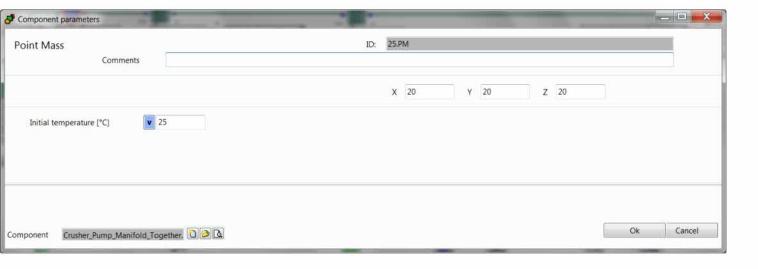






## 25.Point mass: **Component parameters**

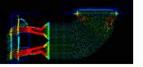




	5.31
Aluminium	▼ 837
	1
	1e+7
	Aluminium

Crusher\_Pump\_Manifold\_Together.kuliPm

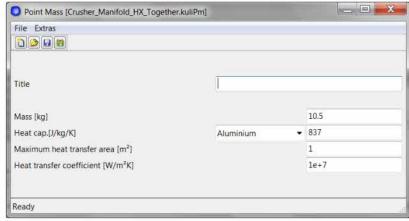




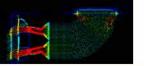
## 24.Point mass: Component parameters



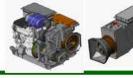




Crusher\_Manifold\_HX\_Together.kuliPm

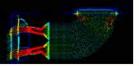


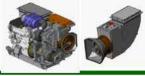
## Calculation Controller: Component parameters



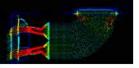
mments				
peration		990 w		
Product(X1 Xn) ▼		Take units into a Output	ccount	
Number of Inputs	2	Output	N. 1	-
		X1	m³/s	
		X2	kPa	300
Gain				

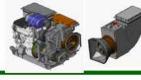
23.Calculation controller			
Operation			
= Sum(X1 Xn) ▼	✓ Take units into a	ccount	
Number of Inputs	Output	kW.	(-)
	X1	kW	i sec
	X2	kW	
Take boundaries into account			
Gain			

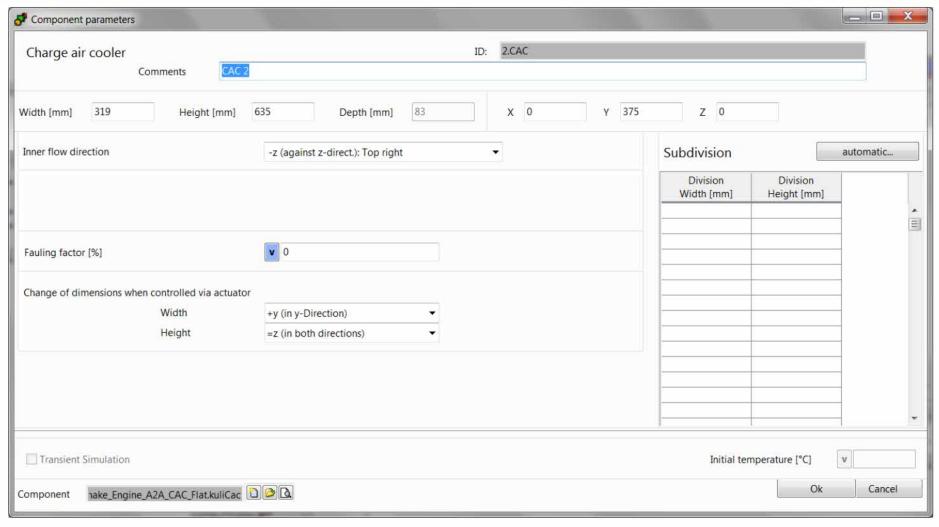




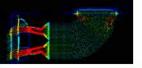
## Charge Air Cooler Radiator Parameters

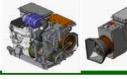




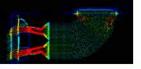


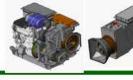


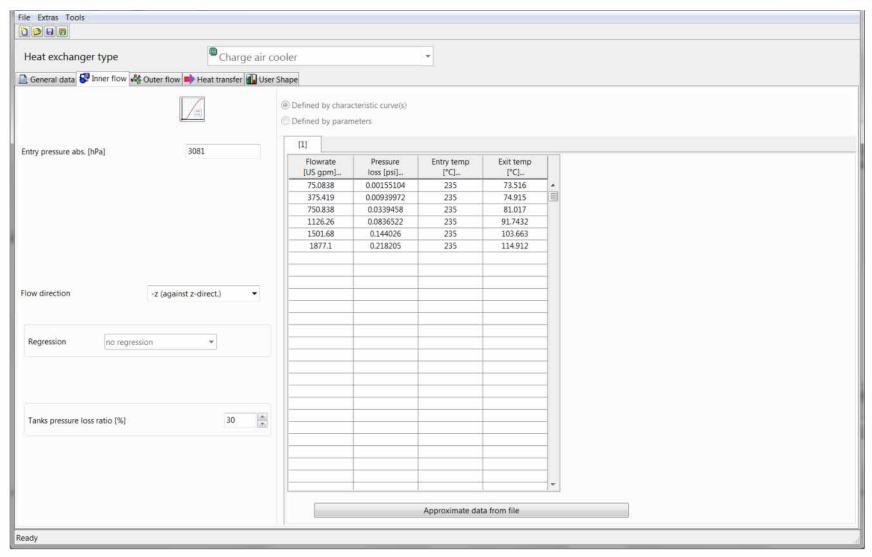


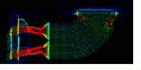


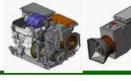
Heat exchanger	type	Charge air cooler	•		
General data	ner flow 🍕 Outer flow 📑	Heat transfer  User Shape			
User Date (0=current)	ECS Donnerstag, 29. Novem	nber 2001 15:37:06	Layout  Standard  U-flow		
Title Memo		<u> </u>	S-flow Passes	i	
10		7	Tube data Overall tube number	20	
Type No.			No of rows of tubes  Tube cross-section [mm²]	326.84	
Manufacturer Series Measrd. data file			Wetted perimeter [mm]	228.8	
Geometric data			Flow properties inner side	<ul><li>unmixed</li></ul>	
Width [mm] Height [mm]	319 635		Thinks of the second of the se	Carried Carried	
Depth [mm]	83			ANALYSIS CONTRACTOR OF THE PROPERTY OF THE PRO	
					hhonors 2 Internet acce
eady					merret

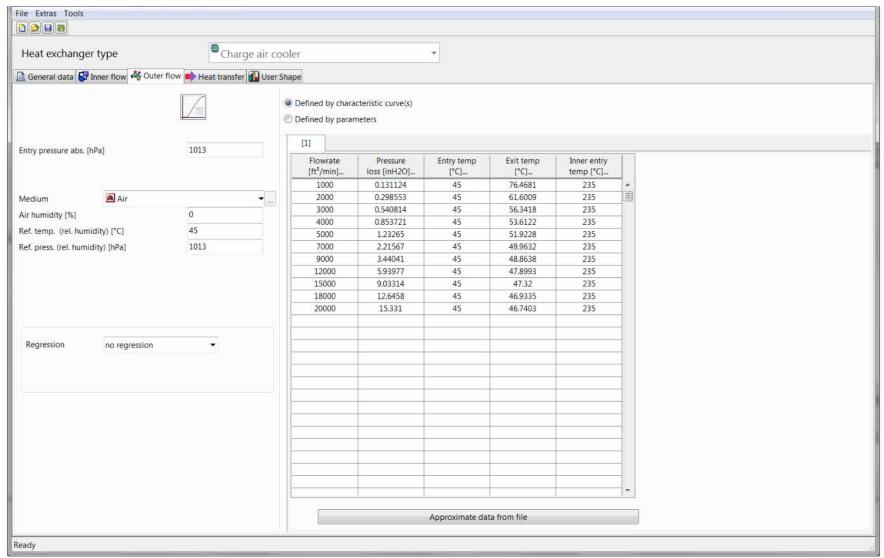






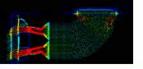




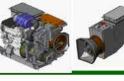


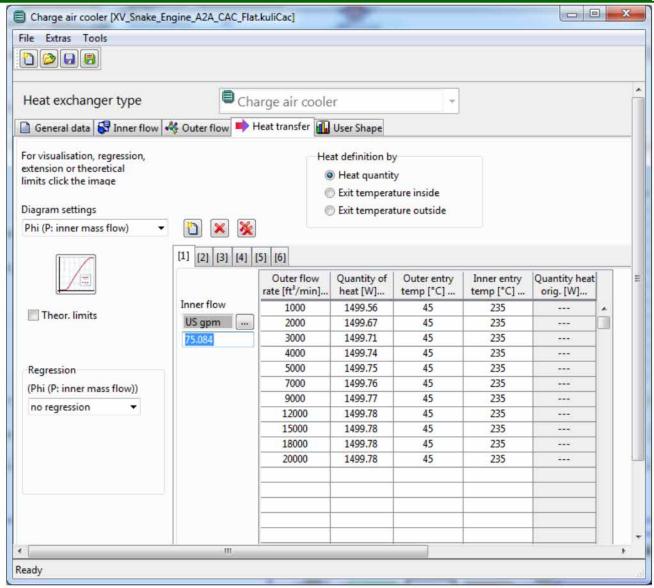
 $XV\_Snake\_Engine\_A2A\_CAC\_Flat.kuliCac$ 

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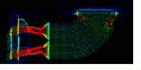




XV\_Snake\_Engine\_A2A\_CAC\_Flat.kuliCac

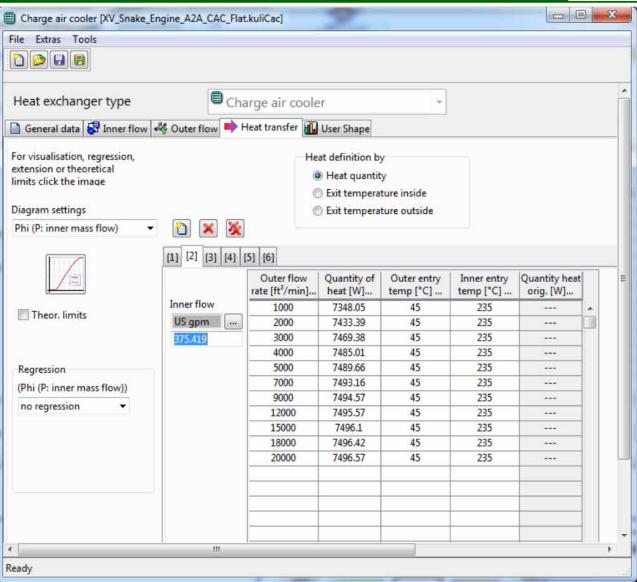
Copyright 2011 Carnegie Mellon



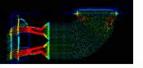


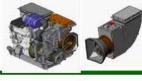


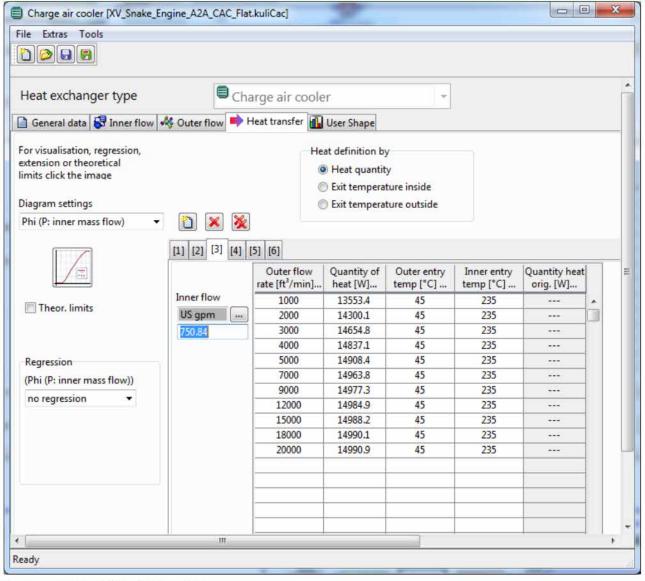










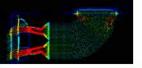


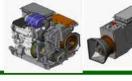
XV\_Snake\_Engine\_A2A\_CAC\_Flat.kuliCac

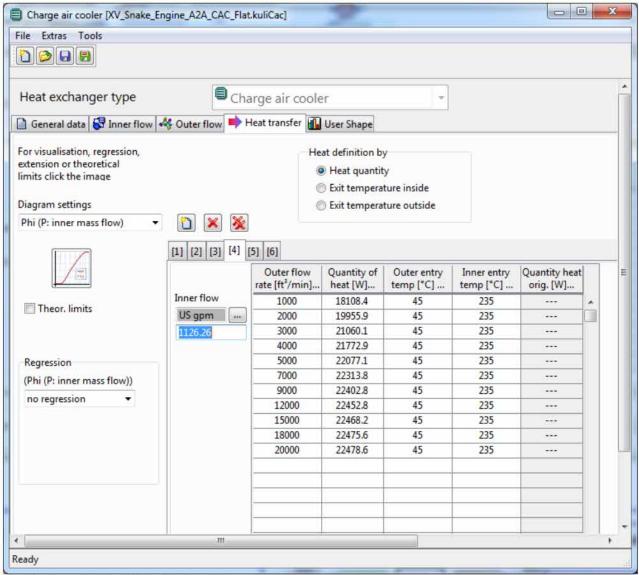




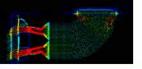
Page 46

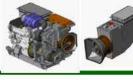


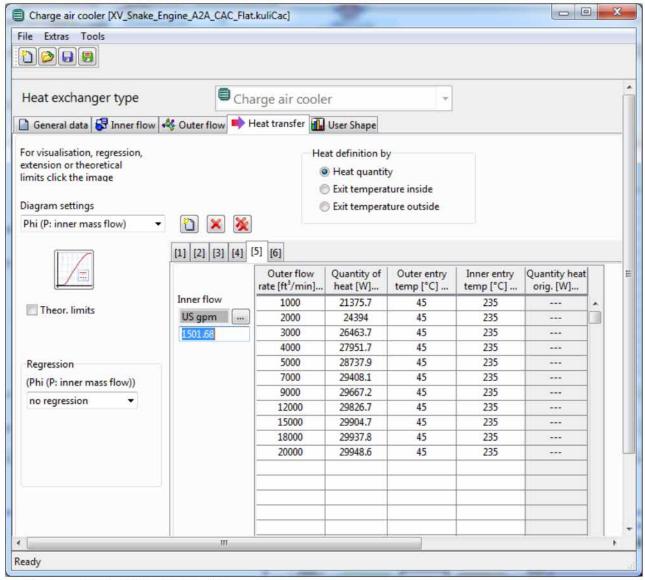






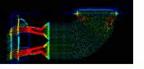


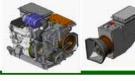


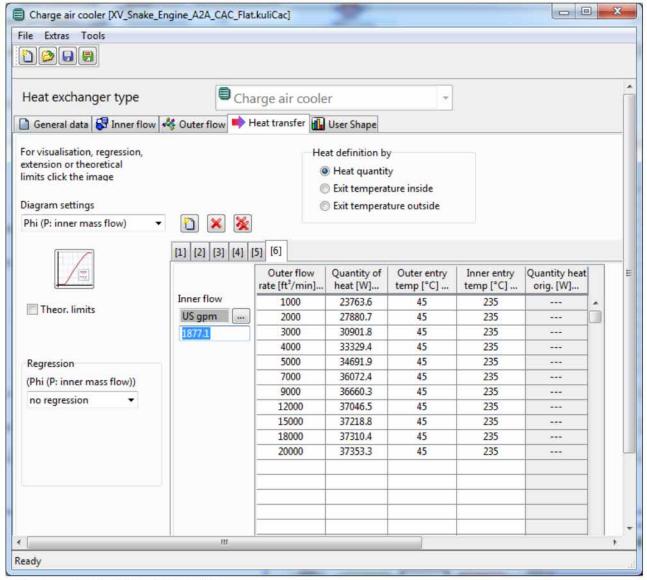






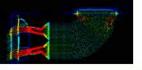




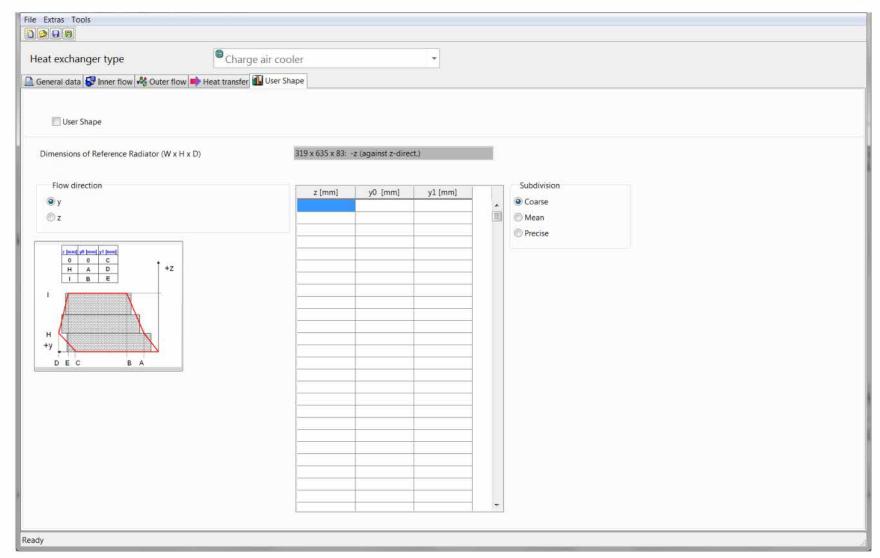






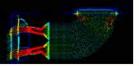


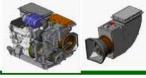




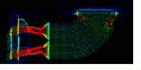
XV\_Snake\_Engine\_A2A\_CAC\_Flat.kuliCac
Copyright 2011 Carnegie Mellon







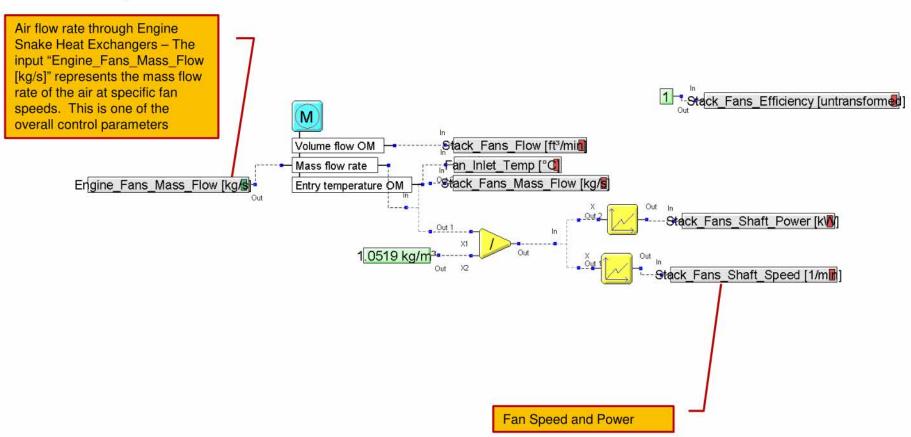
## **Engine Snake Air Flow**

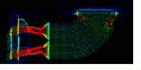


#### **Kuli Engine Snake Air Flow**

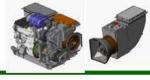


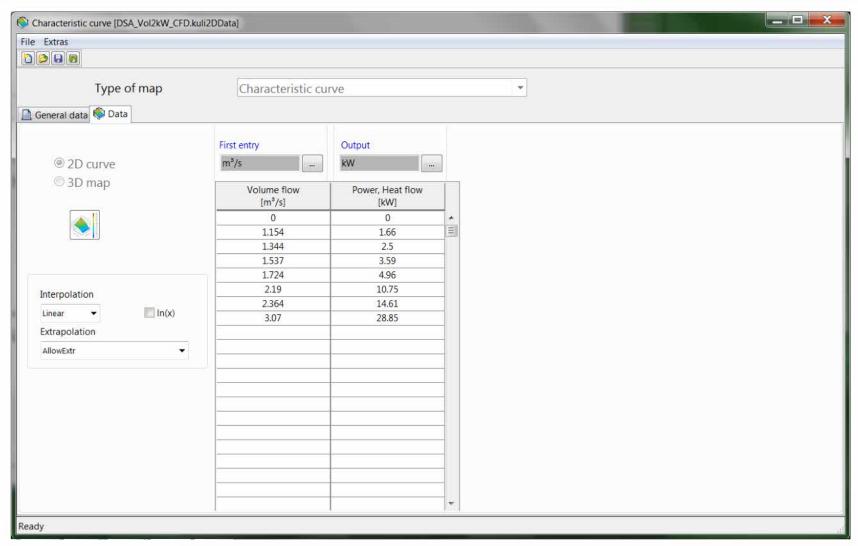
#### Input mass flow rate from Simulink





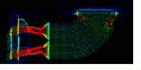
### Kuli Engine Snake Air Flow - Output



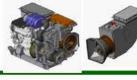


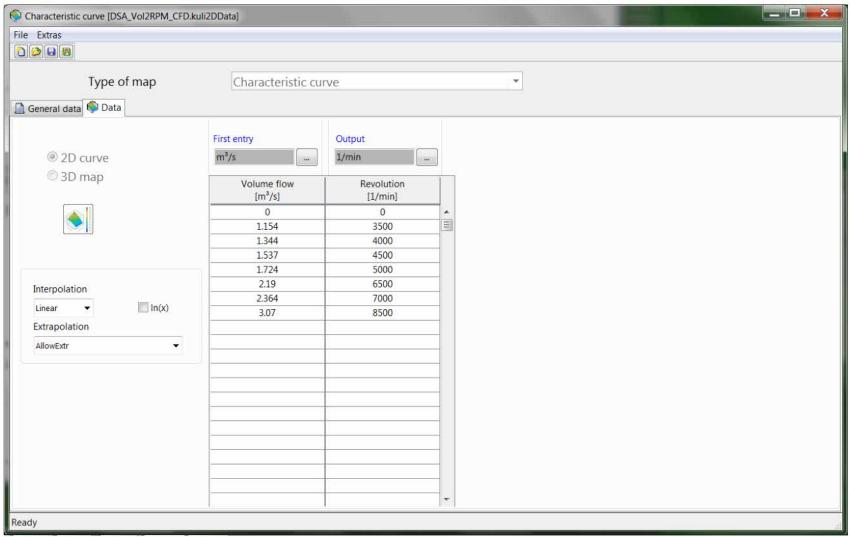
DSA\_Vol2kW\_CFD.kuli2DData





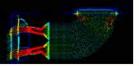
### Kuli Engine Snake Air Flow - Output





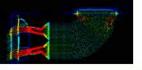
DSA\_Vol2RPM\_CFD.kuli2DData



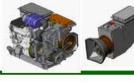




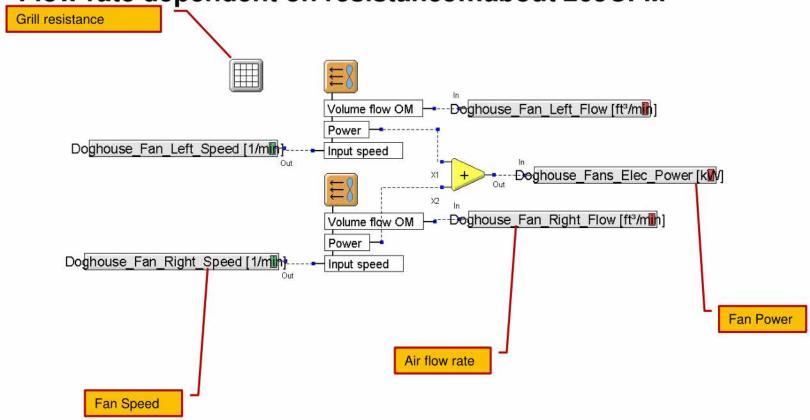
# **Engine Compartment Air Flow**

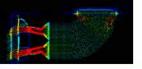


### **Kuli Engine Compartment Fan**

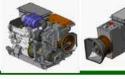


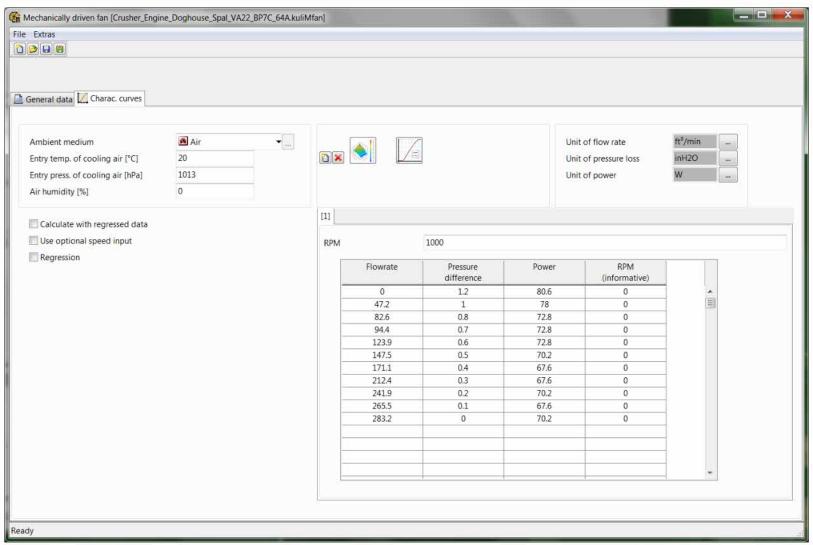
- Pulls air through inlet grill, over engine block then out of engine compartment
- Flow rate dependent on resistance...about 265CFM





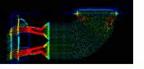
### 7. Mechanically Driven Fan



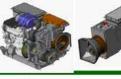


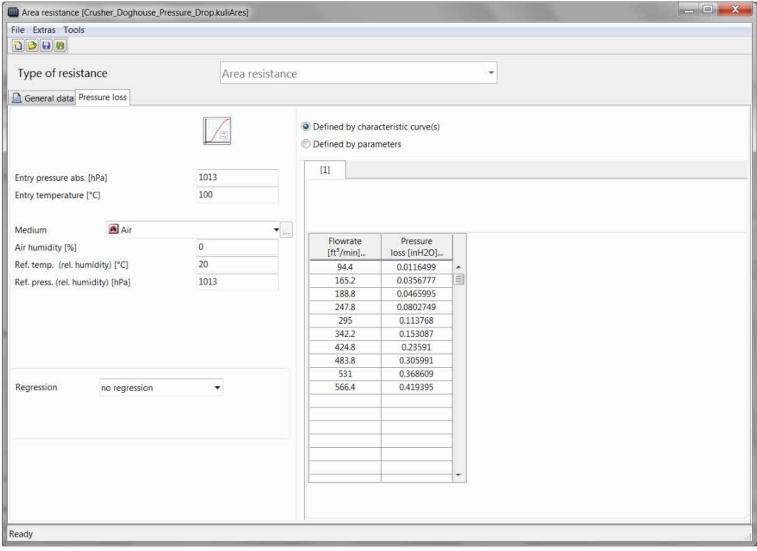
Crusher\_Engine\_Doghouse\_Spal\_VA22\_BP7C\_64A.kuliMfan





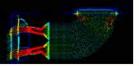
#### 1.Area Resistance

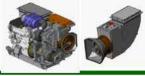




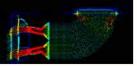
Crusher\_Doghouse\_Pressure\_Drop.kuliAres

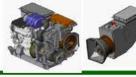




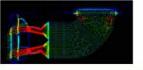


# **Drive Snake Details**





# 85C Loop

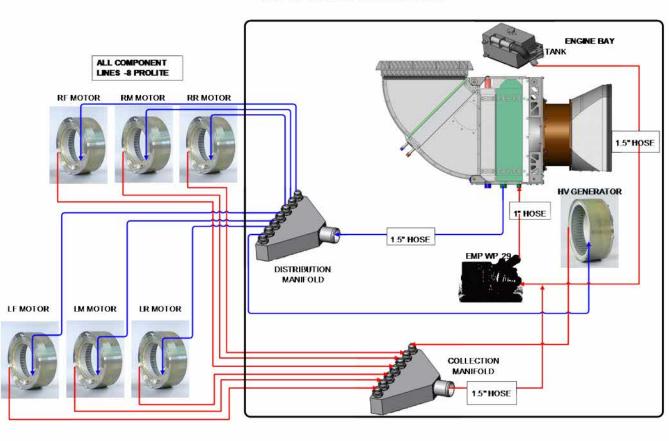


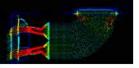
#### XV – 85C Loop



#### 85 C COOLING LOOP

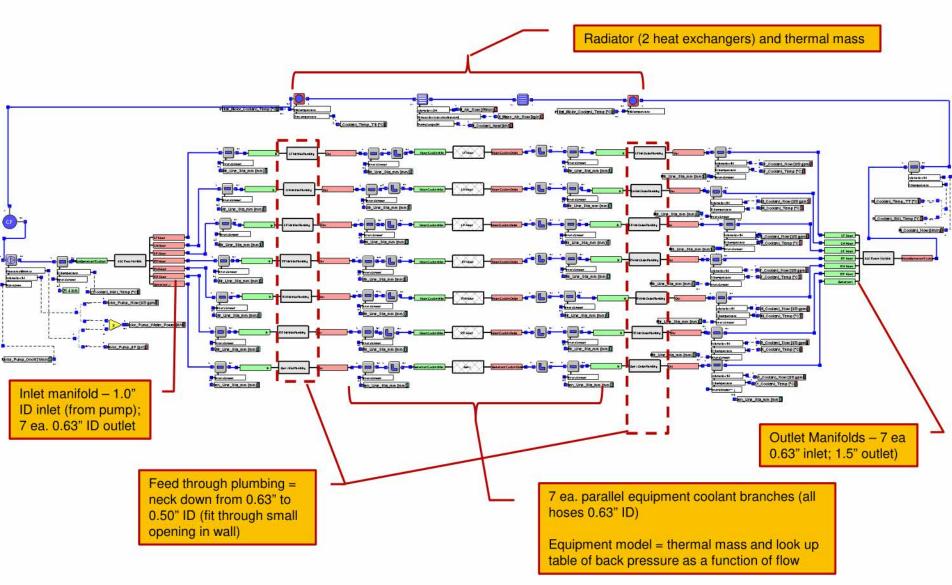
- Max load 80kph, 45C model & actual
- Flow rate has margin, pumps not at full speed
- Loop as thermal margin, other equipment could be added
- Simplest loop

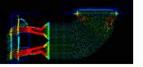




#### Kuli 85C Loop



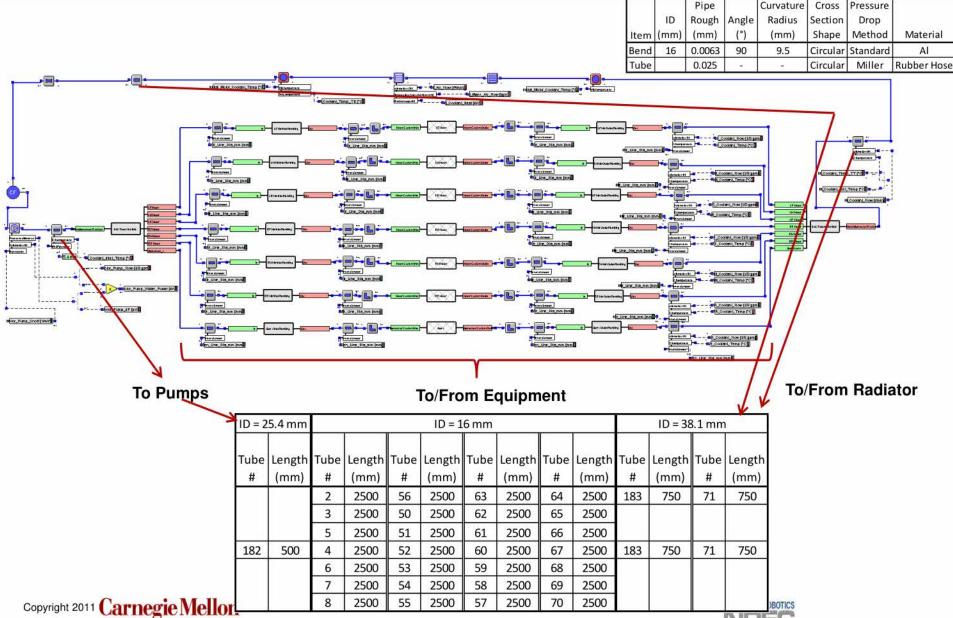


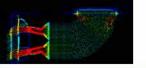


#### Kuli 85C Loop Tubes and Bends

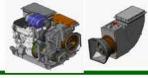


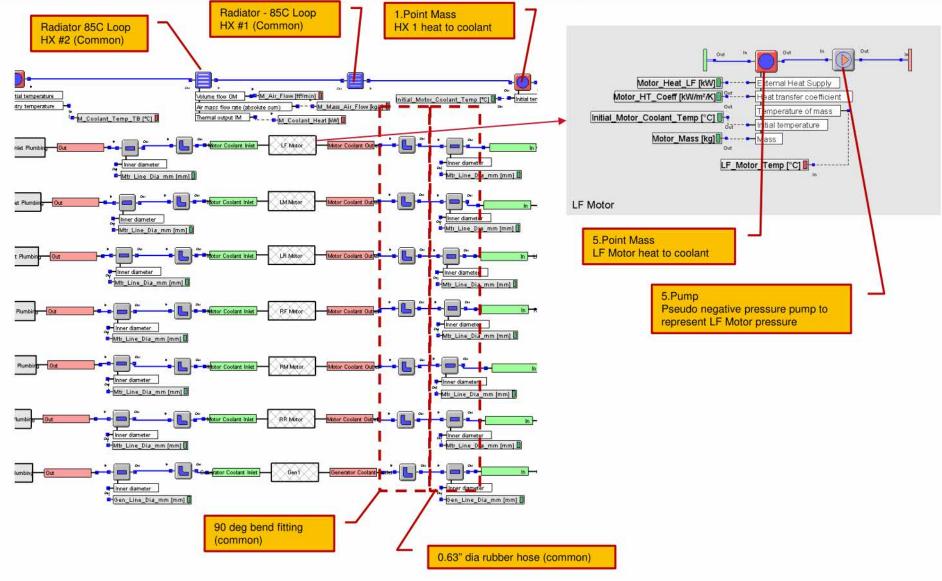


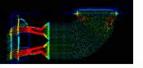




# XV KULI Model – 85C Cooling Loop I/O



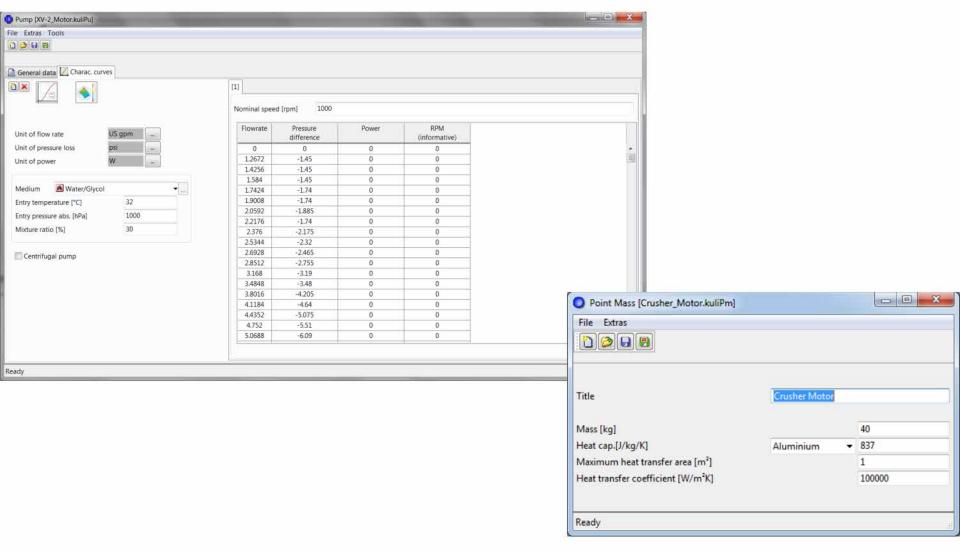




# Motor Back Pressure & Point Mass (Common to all 6 motors)

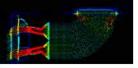






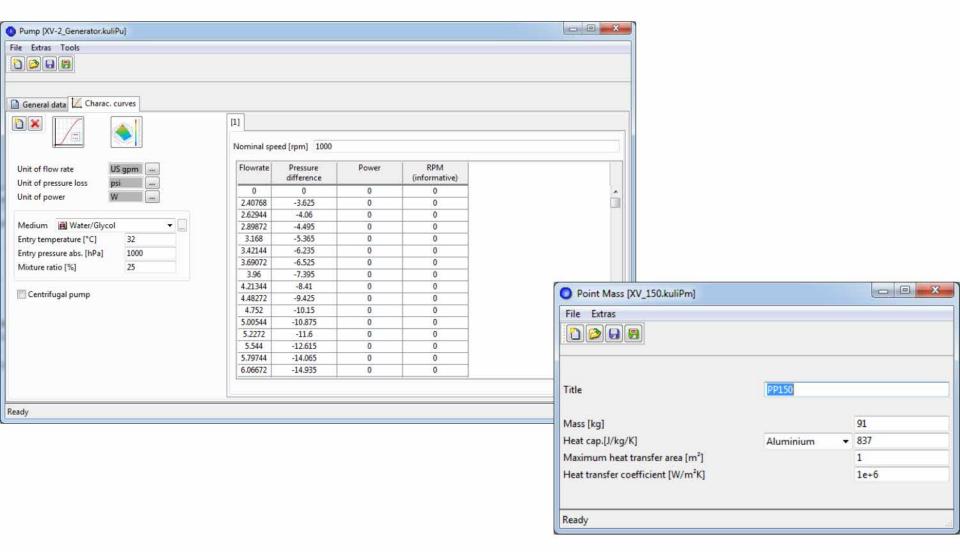
XV-2 Motor.kuliPu





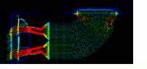
#### **Generator Back Pressure**



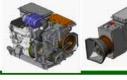


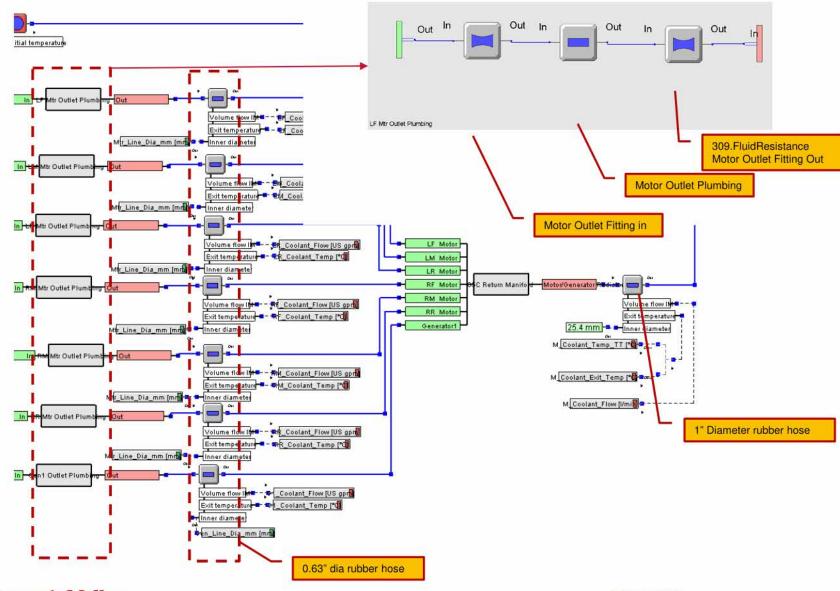
XV-2 Generator.kuliPu

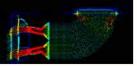




# XV KULI Model – 85C Cooling Loop I/O

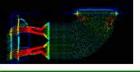




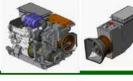




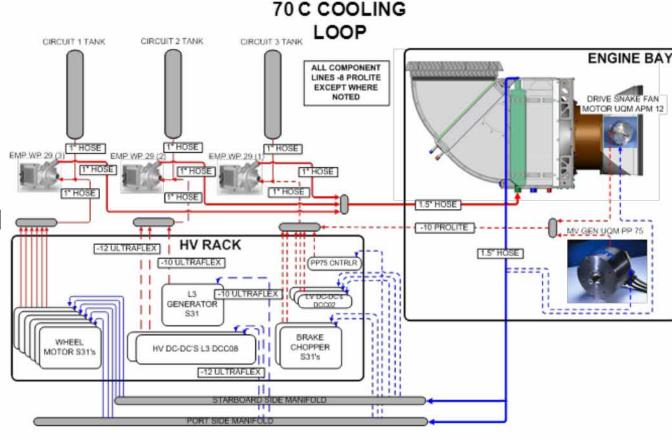
# 70C Loop

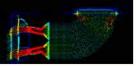


#### XV - 70C Loop

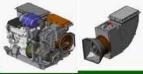


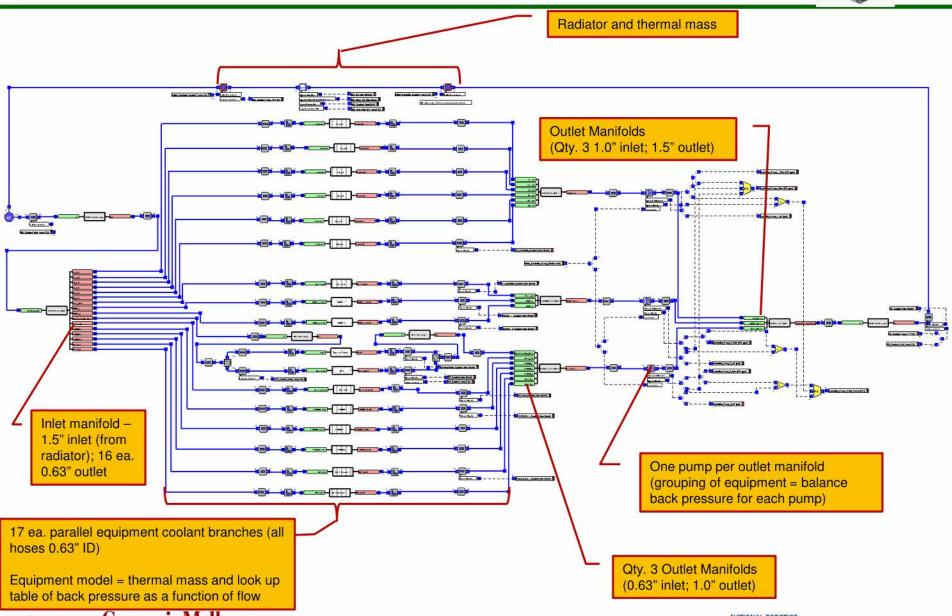
- Max load 80kph,
   45C model & actual
- Flow rate slightly less than needed after quick disconnects installed (losses)
- Loop at limit (model & actual)
- 70C loop limited performance
- Slightly higher coolant flow rate – XV would have run at 45C, full solar



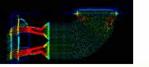


#### Kuli 70C Loop



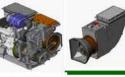


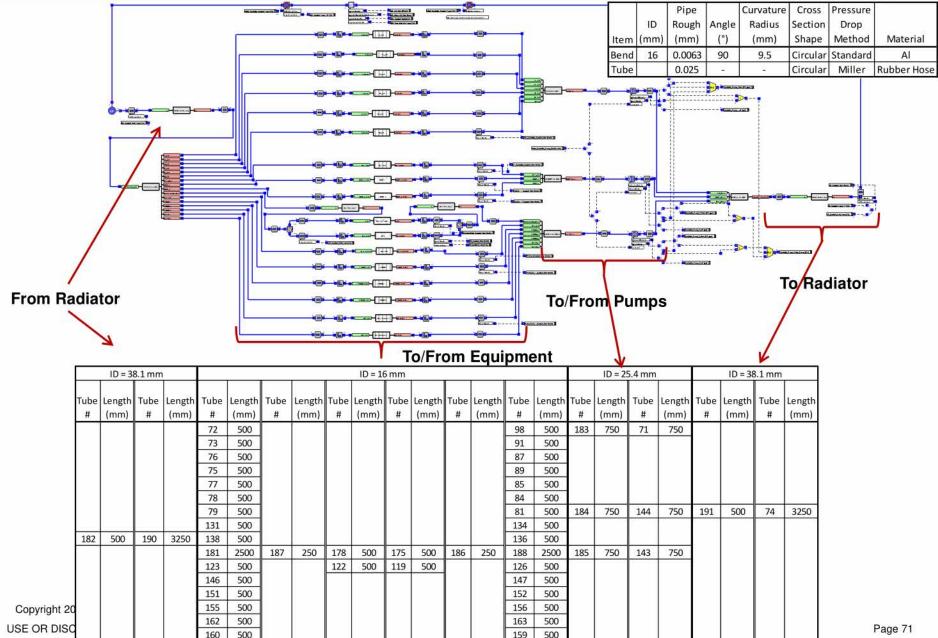
**ENGINEERING CENTER** 

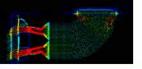


#### Kuli 70C Loop Tubes and Bends

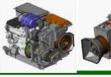


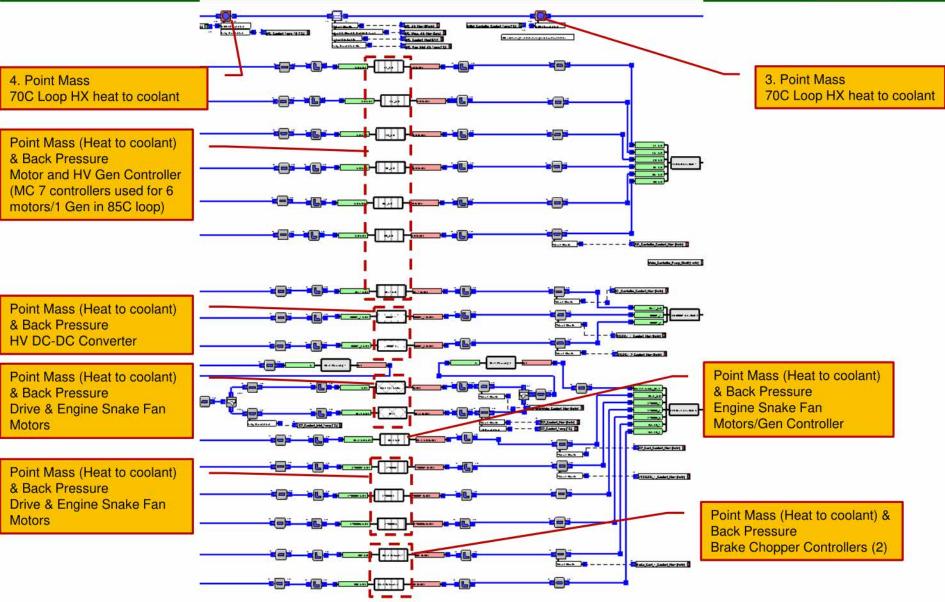


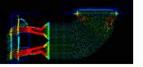




#### Kuli 70C Loop Point Mass & Back Pressure \$\infty\$

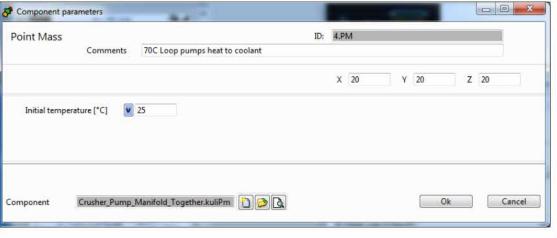


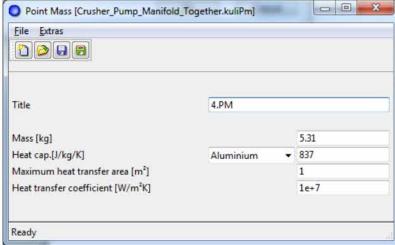


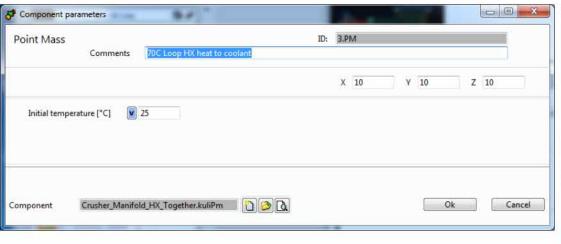


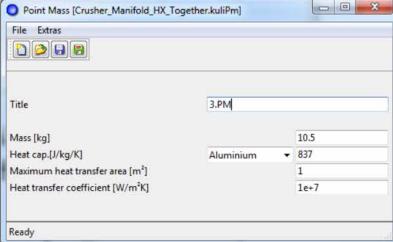
#### **HX Point Mass**





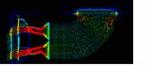






XV-2 Generator.kuliPu

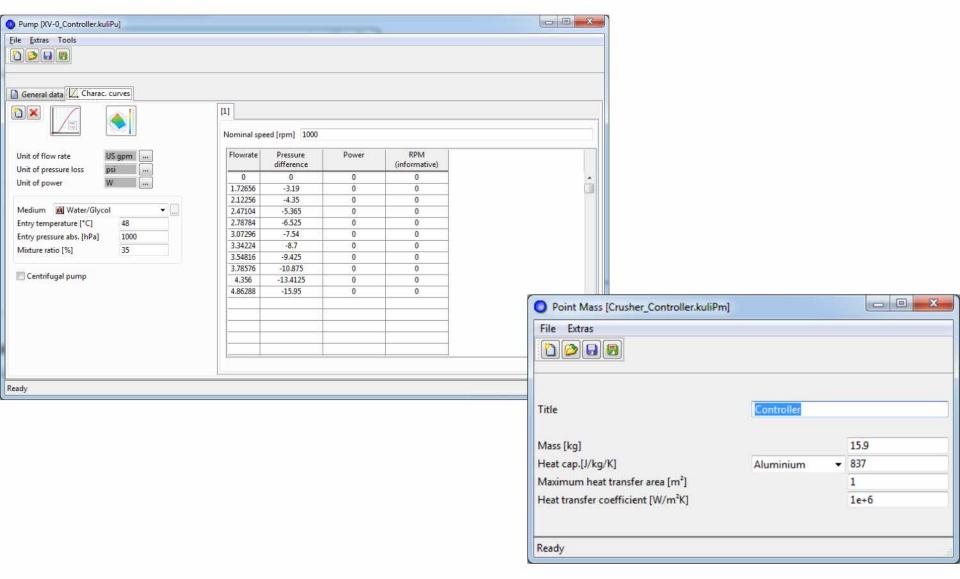


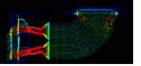


## Motor/Gen1/Brake Chopper Controller Back Pressure & Point Mass (9 Controllers)



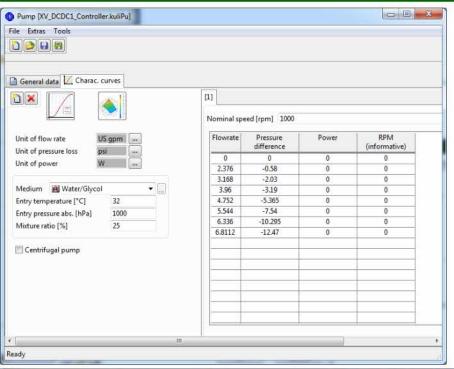






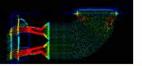
# **HV DC-DC Converter Back Pressure & Point Mass**





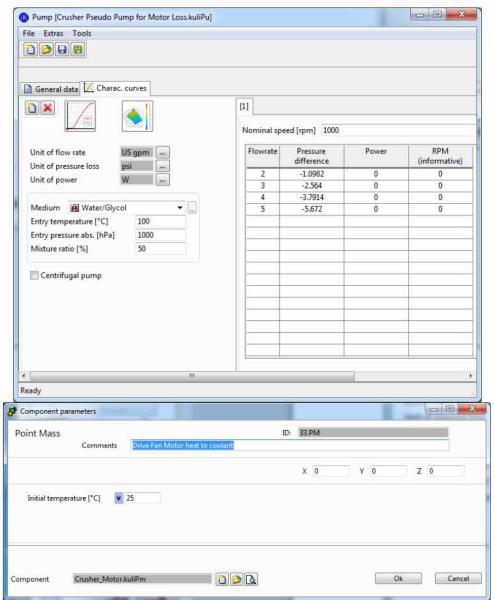
Component parameters		Point Mass [Crusher_Controller.kuliPm]	
Point Mass  Comments   DCDC1-1 heat to coolant	D: 26.PM	File Extras	
	X 0 Y 0 Z 0	Title	Controller
Initial temperature [°C] v 25		Title	Contona
		Mass [kg]	15.9
		Heat cap.[J/kg/K]	Aluminium ▼ 837
		Maximum heat transfer area [m²]	1
		Heat transfer coefficient [W/m²K]	1e+6
Component Crusher_Controller.kuliPm	Ok Cancel		
		Ready	

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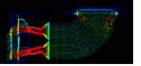


### Drive Snake Fan Motor Back Pressure & Point Mass



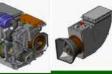


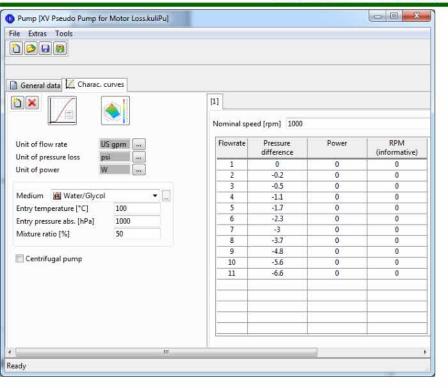
File Extras		
Title	Crusher Motor	
Mass [kg]		40
	Aluminium	▼ 837
Heat cap.[J/kg/K]	Aluminium	
Heat cap.[J/kg/K] Maximum heat transfer area [m²]	Aluminium	1



## Engine Snake Fan Motor/MV Gen **Back Pressure & Point Mass**

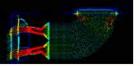






Point Mass  Comments   Gen 2 heat to coolant		ID:	22.PM									
	Comments		2330		Х	0	Υ	0		Z	0	
Initial tempe	rature [°C]	25										
	orașe [ e]											

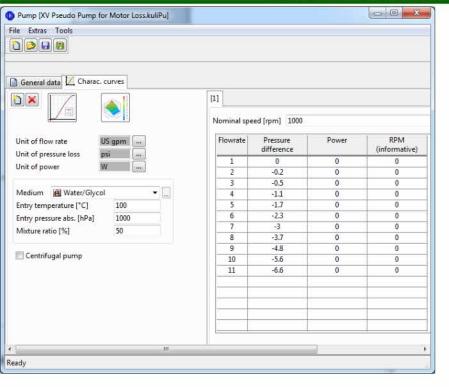
File Extras			
Title	Crusher Motor		
Mass [kg]			40
Heat cap.[J/kg/K]	Aluminium	•	837
Maximum heat transfer area [m²]			1
Heat transfer coefficient [W/m²K]			100000



# Engine Snake Fan Motor/MV Gen Controller Back Pressure & Point Mass

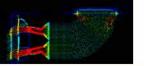




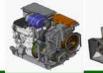


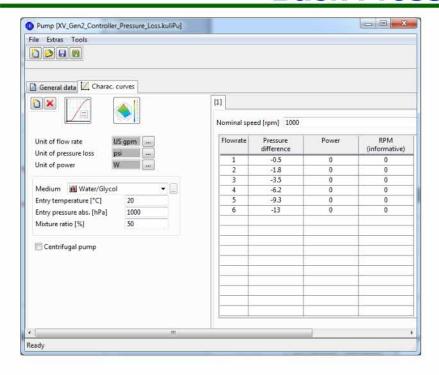
	Х	0	Y 0			
				Z	0	
Initial temperature [°C]   v 25						

File Extras			
Title	Crusher Motor		
Mass [kg]			40
Heat cap.[J/kg/K]	Aluminium	•	837
Maximum heat transfer area [m²]			1
Heat transfer coefficient [W/m²K]			100000

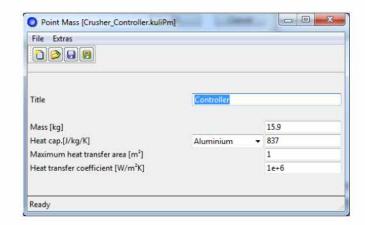


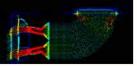
# LV DC-DC Converter Back Pressure & Point Mass

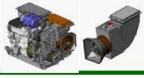




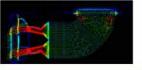
Point Mass		ID: eat to coplant	D: 28.PM							
			Х	0		0		z	0	j
Initial temp	perature [°C] 25									







## **Sub-Ambient Loop**



#### XV – Sub-Ambient Loop

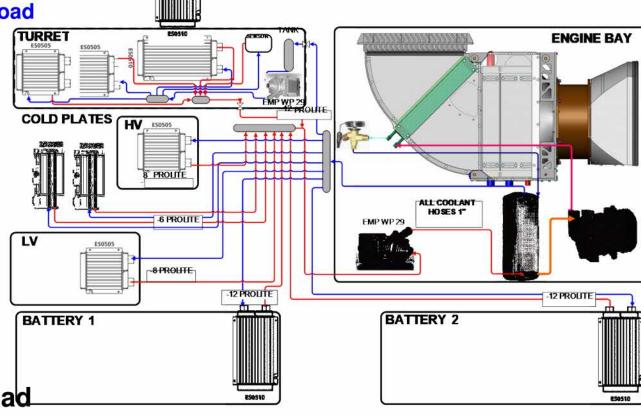


#### Capacity

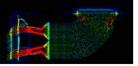
- → Max Eqpt & Vehicle Load
- → 45C ambient w/ Solar load

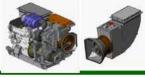
#### Air over heat xchg

- → Turret = all mission equipment
- $\rightarrow$  LV = LV PDU
- $\rightarrow$  HV = HV PDU
- → Battery Packs
- Cold plates = Ctrls
  - → Drive Snake Fan
  - → Compressor
- 2<sup>nd</sup> Turret no eqpt
- Model ~ actual full load
- Some margin in subambient

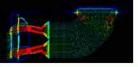


SUB-AMBIENT COOLING LOOP

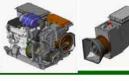




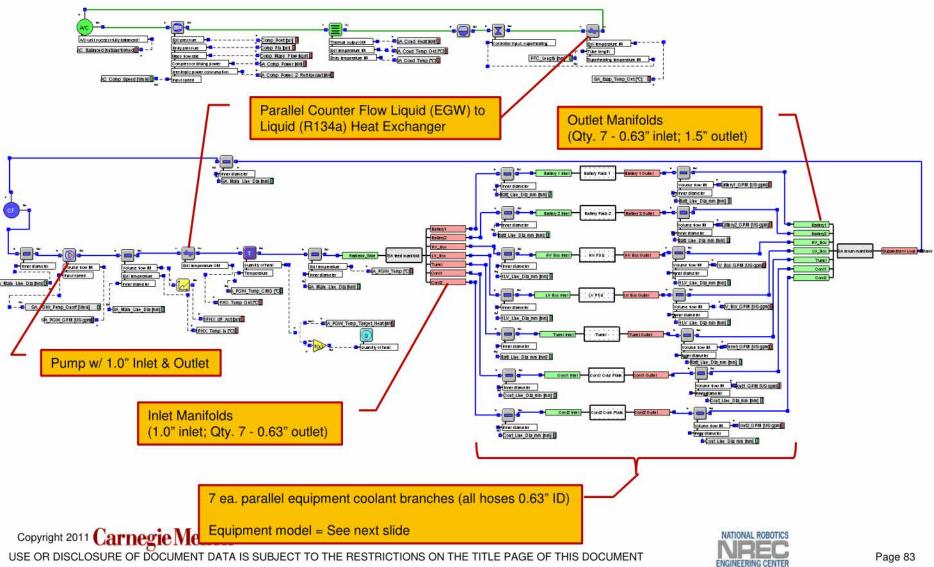
## **Sub-Ambient Loop** - EGW Side

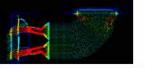


#### Kuli Sub-ambient Loop

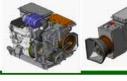


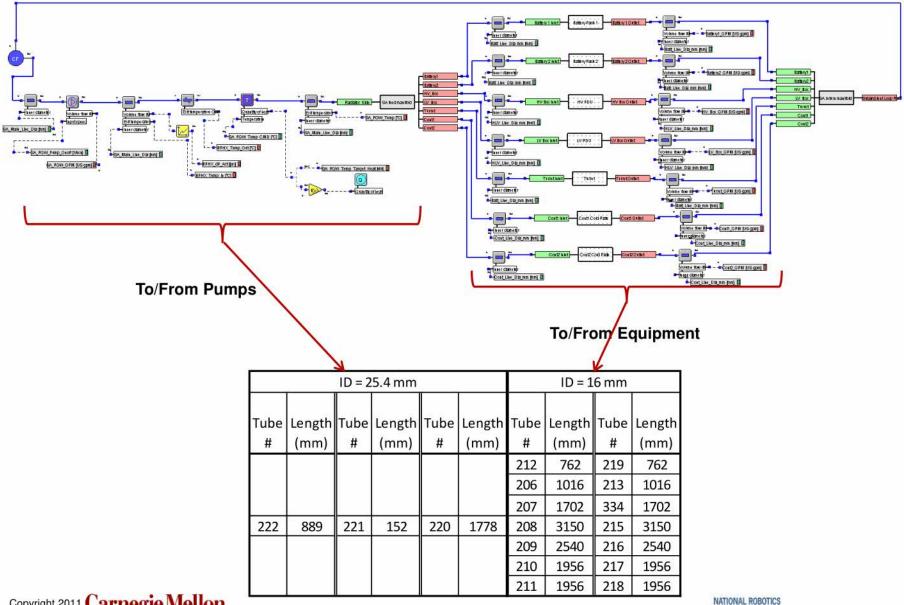
#### HVAC Loop

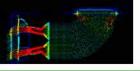




#### Kuli Sub-ambient Loop - Hoses



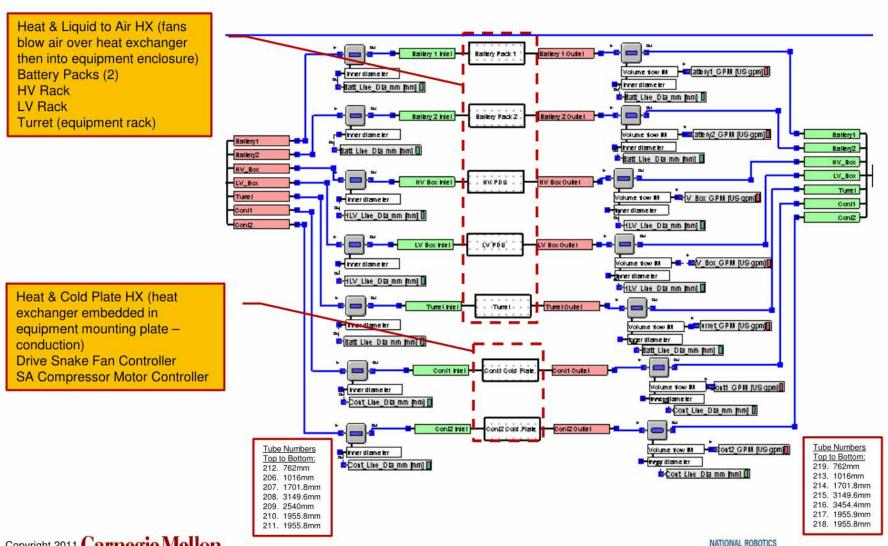


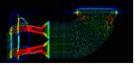


#### Kuli Sub-ambient Loop

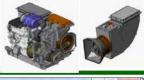


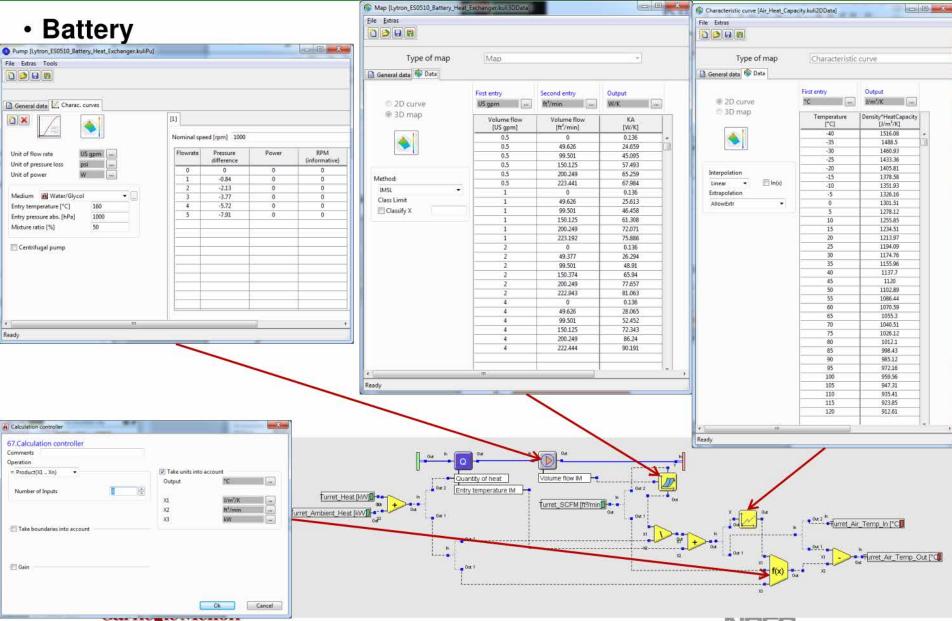
#### Sub-ambient EGW loop – 2 types of component heat exchangers

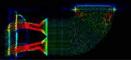




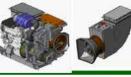
### Kuli Sub-ambient Loop – Battery X 2

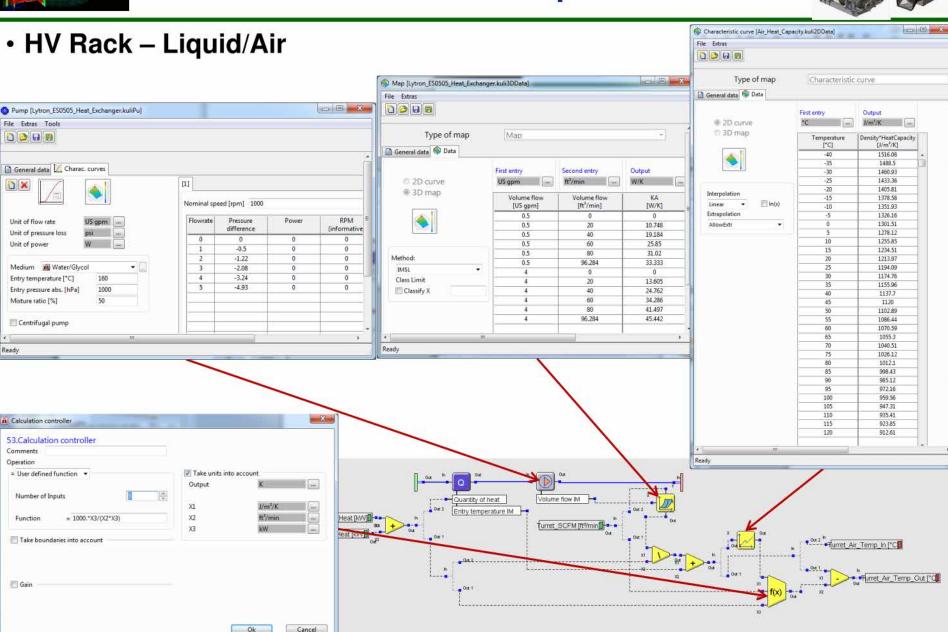


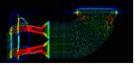




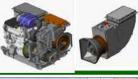
## Kuli Sub-ambient Loop – HV Rack

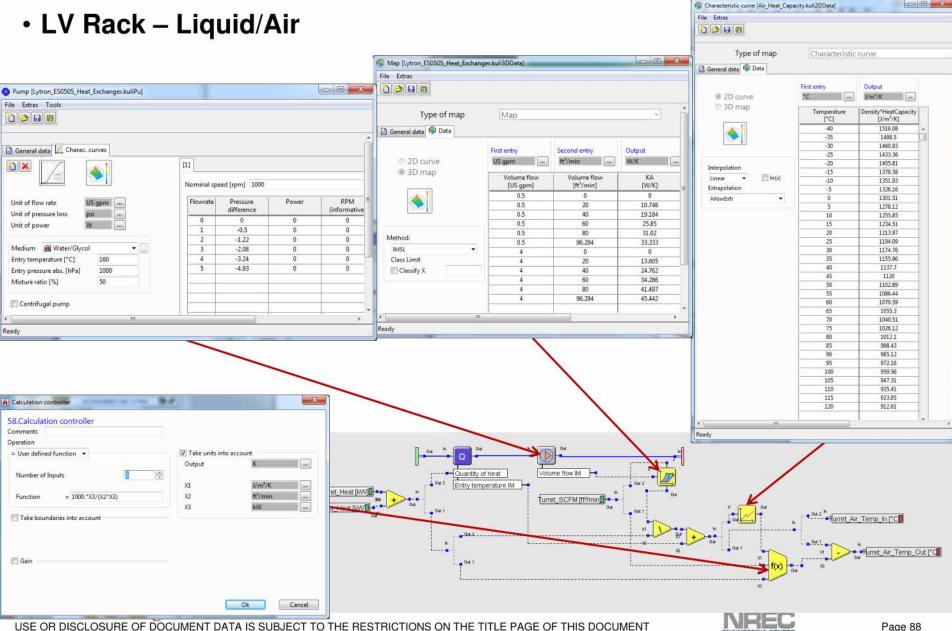


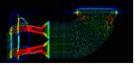




#### Kuli Sub-ambient Loop – LV Rack

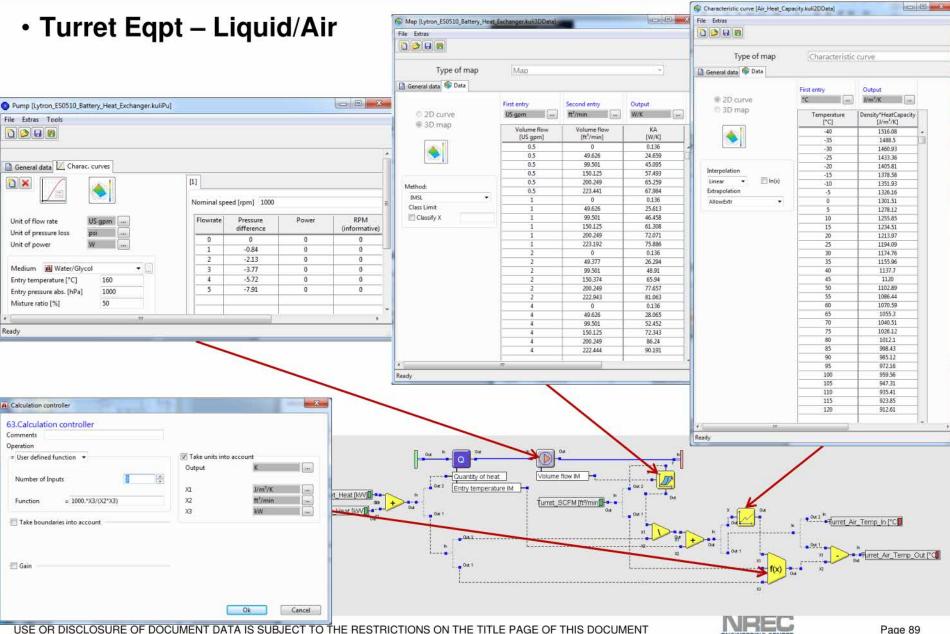


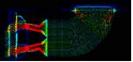




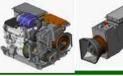
### Kuli Sub-ambient Loop – Turret

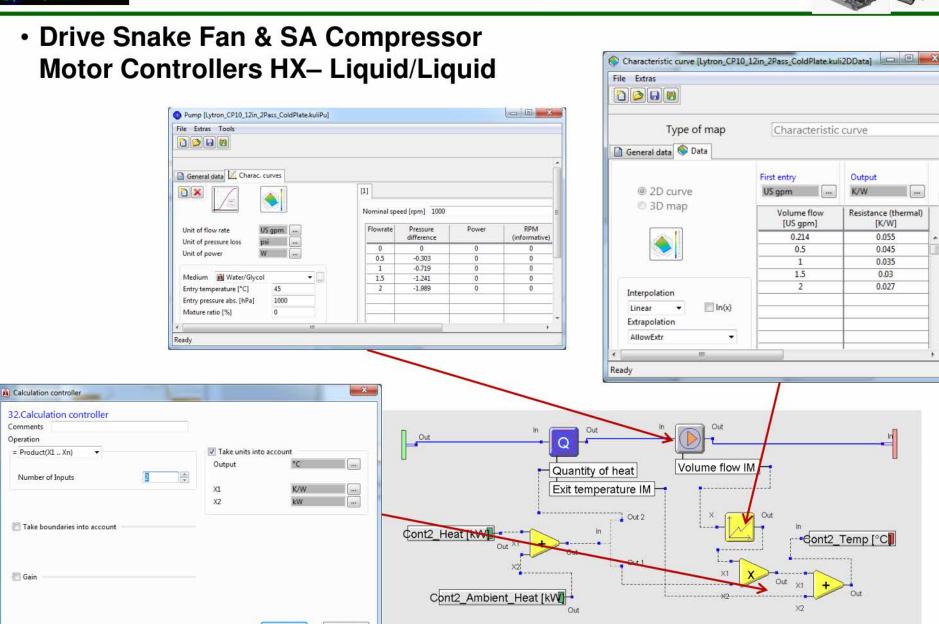




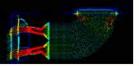


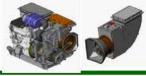
### Kuli Sub-ambient Loop - Cont 1 & 2



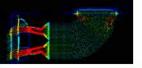


ENGINEERING CENTER

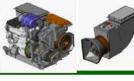


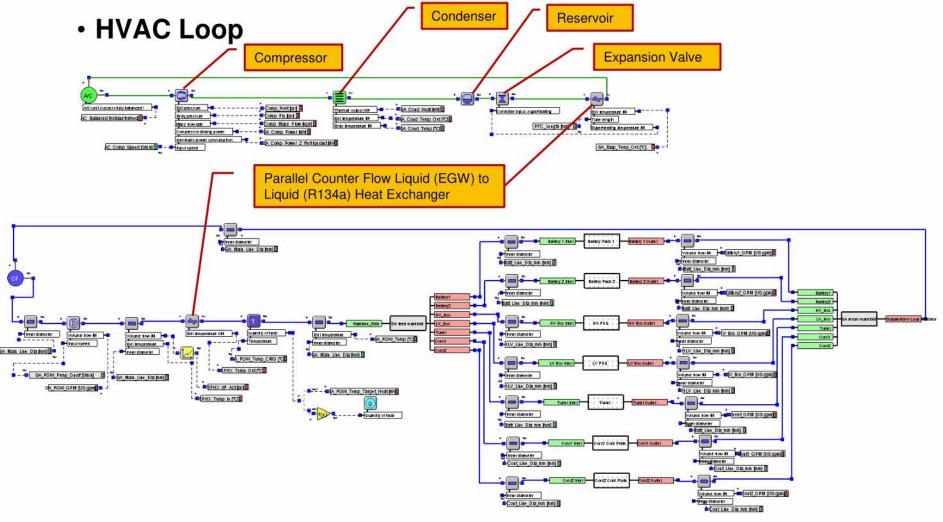


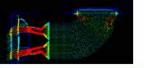
### Sub-Ambient Loop – R134a Side



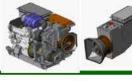
### Kuli Sub-ambient Loop

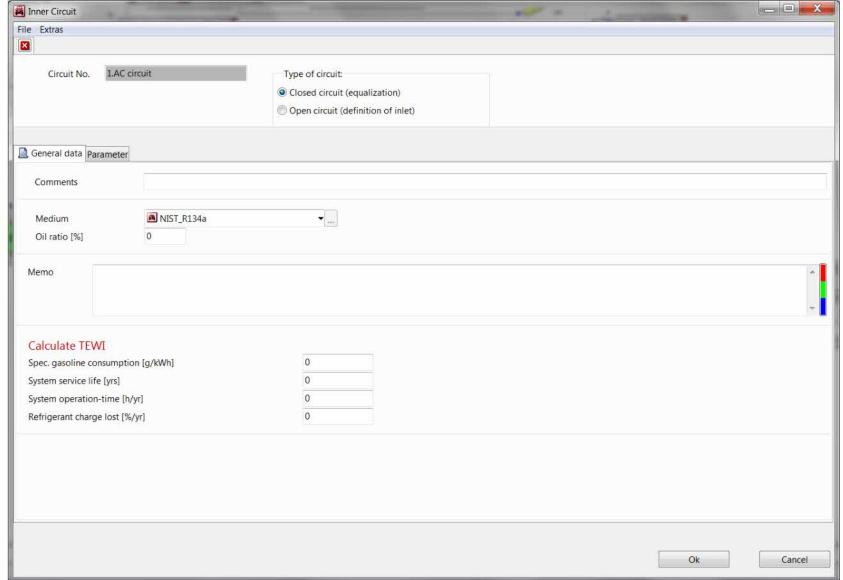


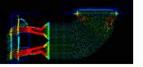




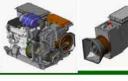
### 1.AC Circuit: General data

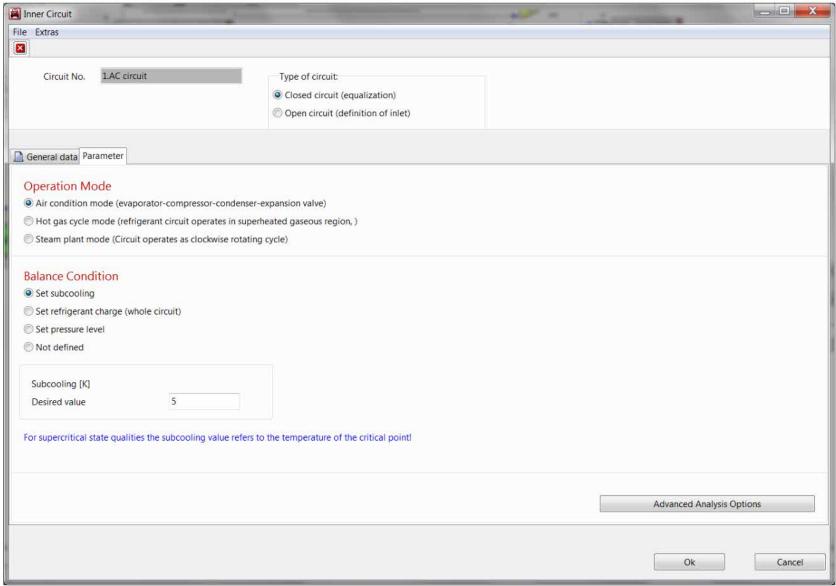


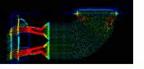




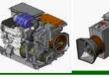
### 1.AC Circuit: Parameter

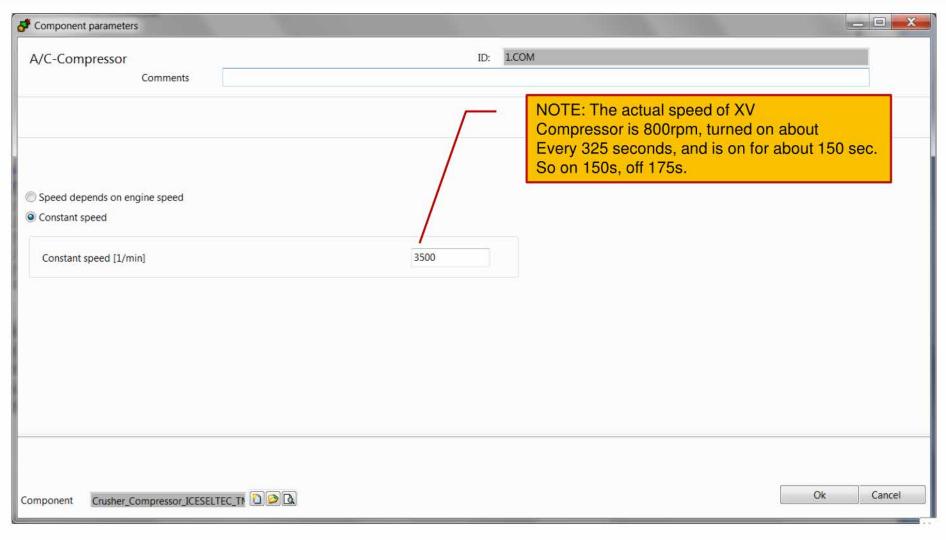




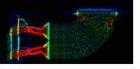


### 1.A/C-Compressor: Component parameters



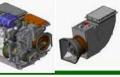


Crusher\_Compressor\_ICESELTEC\_TM-31\_adjusted.kuliCom



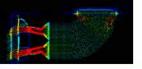
### 1.A/C-Compressor: Component parameters





Compressor [Crusher_Compressor	or_ICESELTEC_TM-31_adjusted.kuliCom]			-				X
File Extras								
General data Charac, curves Co	ontrol characteristic							
	Characteristic curves based model	Analytical based model						
3D Data	Unit of compressor speed 1/min						char, curve interpola	ation
[1] [2] [2] [4]							SplineLin ▼	
[1] [2] [3] [4]			Compressor speed	Volumetric efficiency[-]	Isentropic efficiency [-]		Extrapolation  GetEndPoint ▼	
			1000	0.745	0.521	- ,		
Pressure ratio			1500	0.6835	0.49	E	Œ	
	0		2000	0.622	0.459			/B
4.75			3000	0.5	0.397			,
0								
							Volumetric efficiency	•
						-		
						E COURT		
Coefficient c1 0.87282	parameters: mech_eff = c1 + c2*ln(m / m_max)			Use defa	ALCO DE LOS			
- NORTH-PERSONAL DESCRIPTION DESCRIPTION				Use detail	uit values			
Coefficient c2 0.17766	9							
# Note to								
Ready								

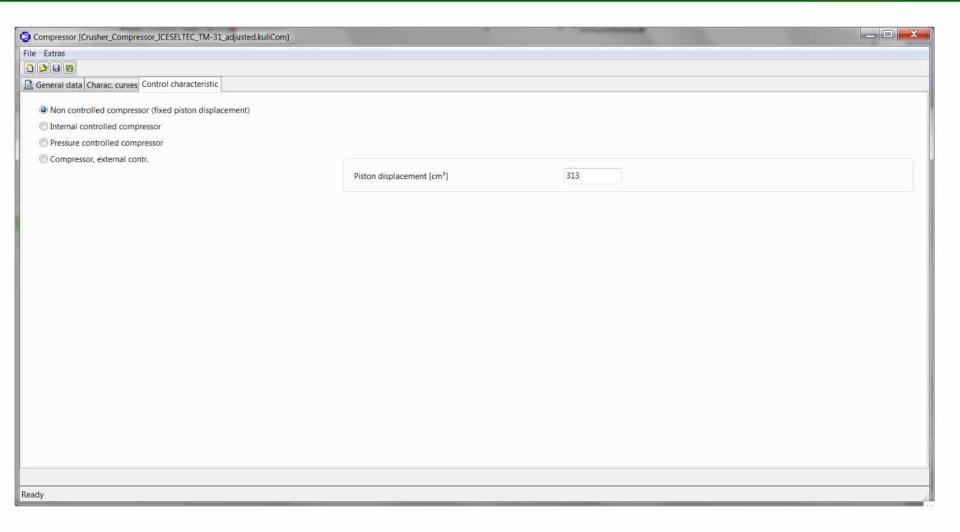
Crusher\_Compressor\_ICESELTEC\_TM-31\_adjusted.kuliCom



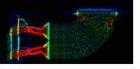
### 1.A/C-Compressor: Component parameters

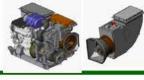




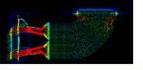


Crusher\_Compressor\_ICESELTEC\_TM-31\_adjusted.kuliCom

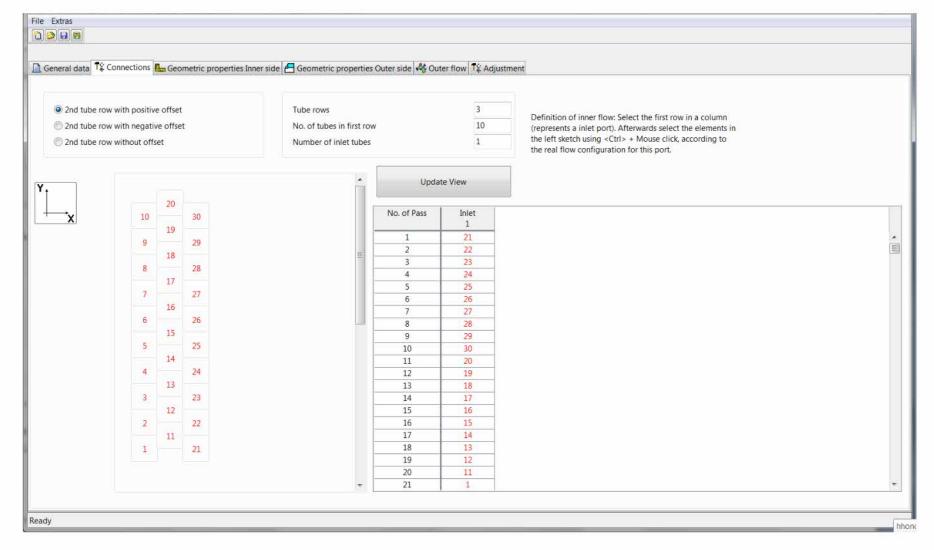




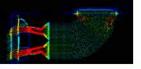
Component parameters	NAME OF TAXABLE	1		100	SHEET, S.	X
Condenser Comments		ID:	1,CND			
Width [mm] 319 Height [mm]	Depth [mm]	83	х 500 ү	375 Z 635		
				Subdivision		automatic
				Division Width [mm]	Division Height [mm]	
Inlet pos. inner medium	Top right	:•				<u> </u>
Fauling factor [%]	V					-
						-
						-
						-
Transient Simulation				Initial to	emperature [°C]	v
Component ke_Drive_Condenser_TKPIT.kuliCnd					Ok	Cancel

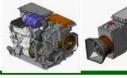




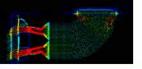


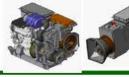


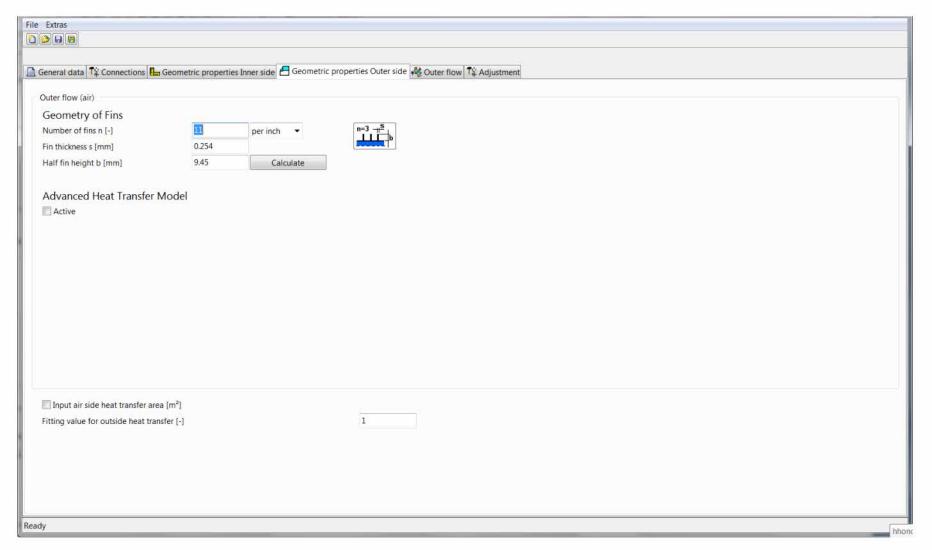




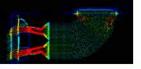
er flow (refrigerant)		
eometry of Tube		Examples Tube Pipe  1 Pipe Row; 4 Pipe Rows Wall Thickness
all Thickness [mm]	0.5	1 Pipe Row; 4 Pipe Rows Wall Thickness 2 Pipe Rows, 2 Fins/Pipe 2 Pipe Rows, 4 Fins/Pipe
eometry of Pipe	Non circular	
ameter [mm]	11.88	
pe roughness [mm]	0.002	
Input ref. side heat transfer are		
ting value for inside heat transf ting value for inside pressure lo		1

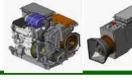


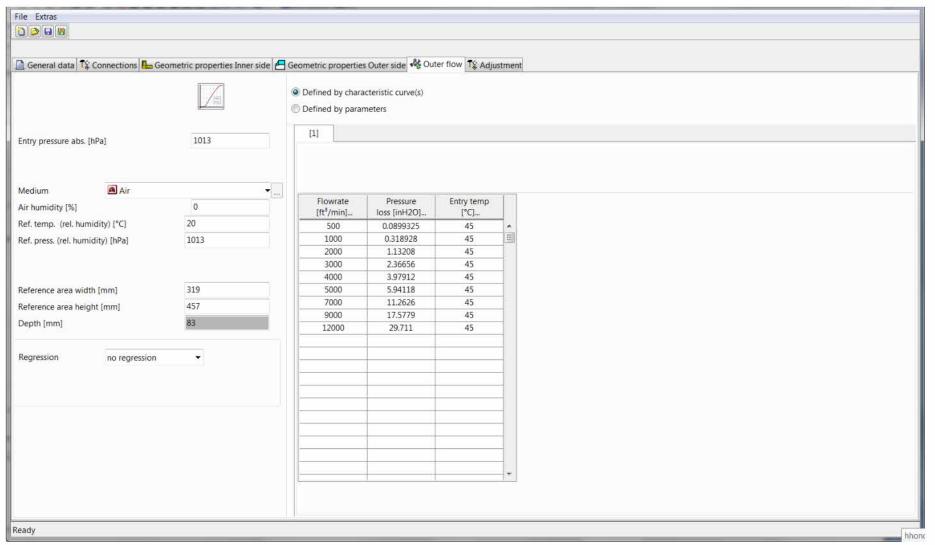


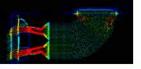


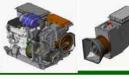


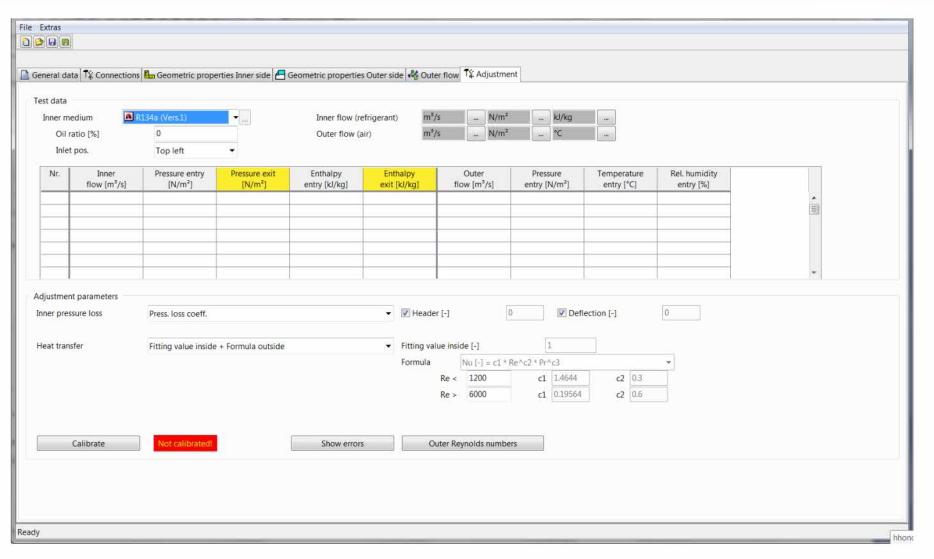




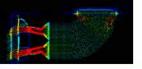




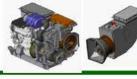






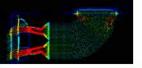


### 1.Storage Tank: Component parameters

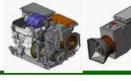




Integrated\_Receiver.sto



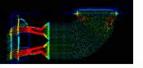
### 1.Storage Tank: Component parameters



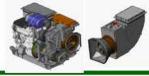
Storage tank [Integra	ted_Receiver.sto]			X
File Extras				
User	ECS-Steyr	Volume [cm³]	200	
Date (0=current)	2009			
Title	High pressure receiver			
Memo		*		
Туре	Integrated receiver	-		
No.	Example			
Manufacturer	Example			
Series	Example			
Measrd. data file	Example			
Vapour at outlet (A  Liquid at outlet (Hi  Storage tank  Consider heat trans	igh pressure receiver)	D		
Ready				

Integrated\_Receiver.sto



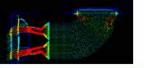


### 1.A/C-Expansion-Valve: **Component parameters**



Component parameters		_ = X
A/C-Expansion-valve  Comments	ID: 1.EXV	
Component Crusher_Expansion_Valve_RD-5-68		Ok Cancel

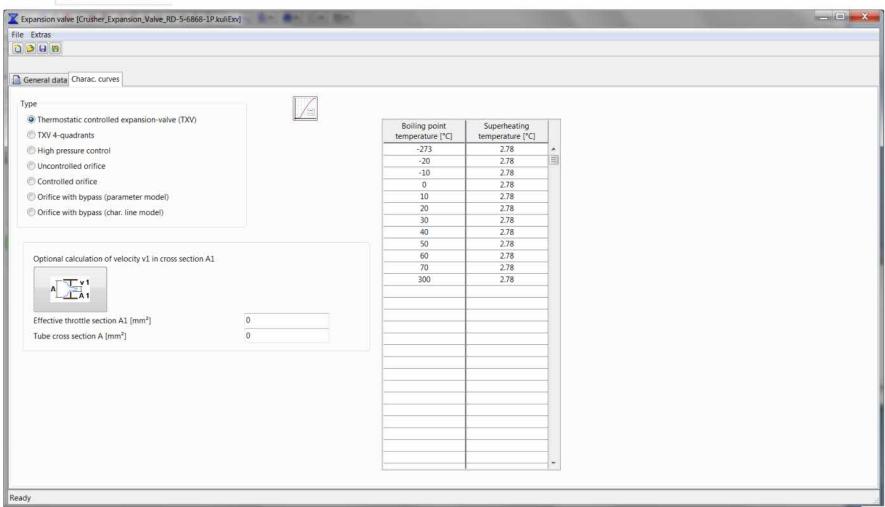
Crusher\_Expansion\_Valve\_RD-5-6868-1P.kuliExv



# 1.A/C-Expansion-Valve: Component parameters

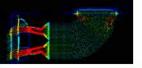


Type: RD-5-6868-1P

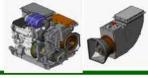


Crusher\_Expansion\_Valve\_RD-5-6868-1P.kuliExv



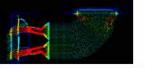


### 1. Refrigerant PFC: **Component parameters**

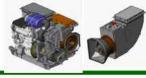


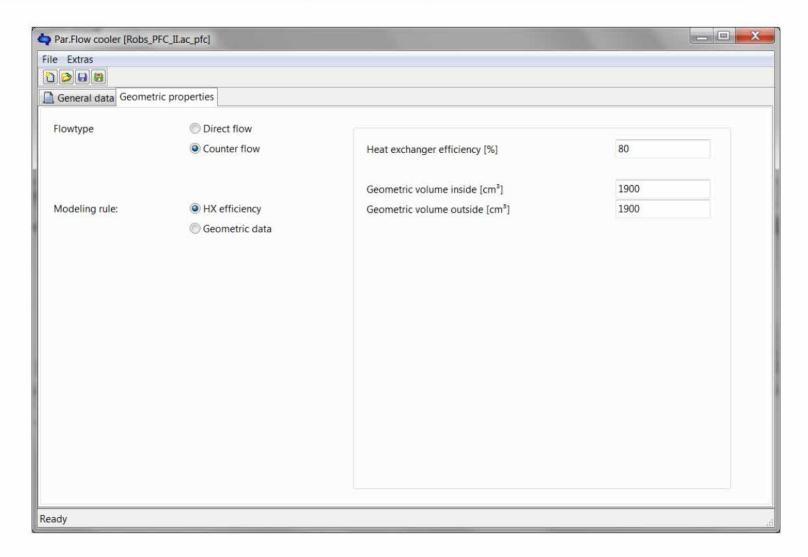
Component parameters		□ X
Refrigerant PFC	ID: 1.ACPFC	
Component Robs_PFC_ILac_pfc	Ok	Cancel

Robs\_PFC\_II.ac\_pfc



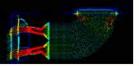
# 1. Refrigerant PFC: Component parameters

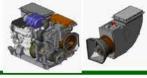




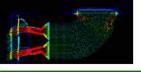
Robs\_PFC\_II.ac\_pfc



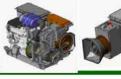




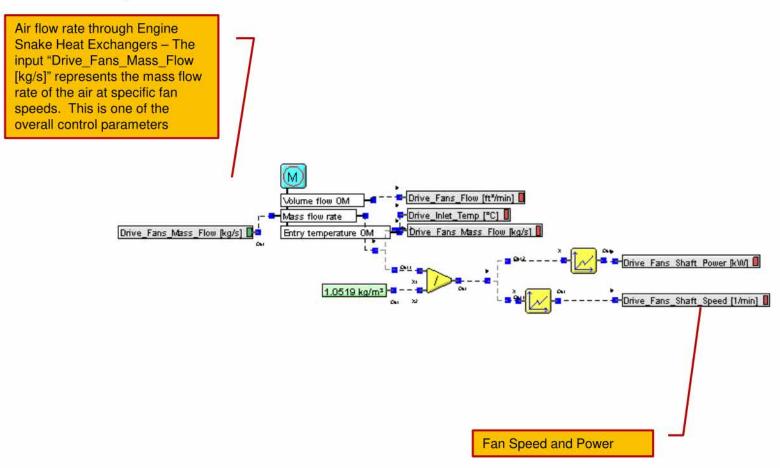
# Drive Snake Air Flow

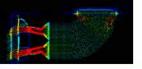


#### Kuli Drive Snake Air Flow

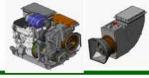


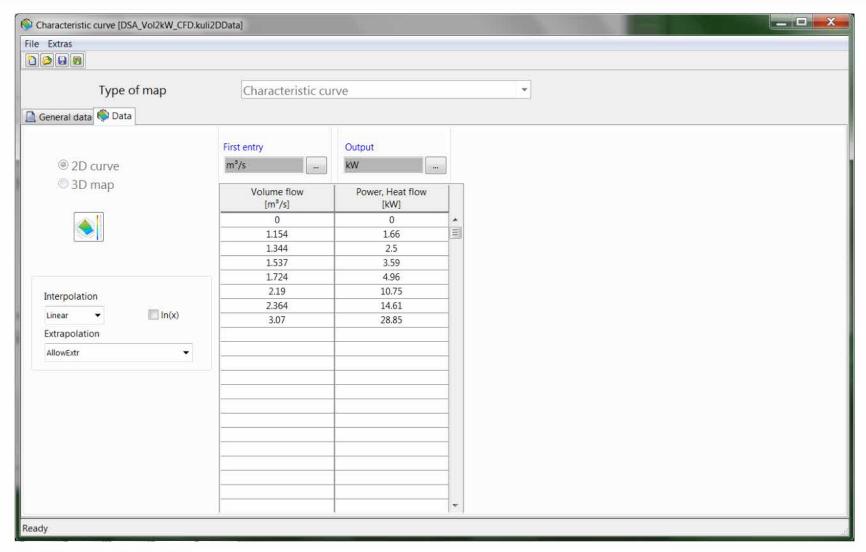
### Input mass flow rate from Simulink





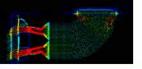
### **Kuli Drive Snake Air Flow - Output**



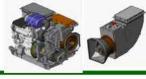


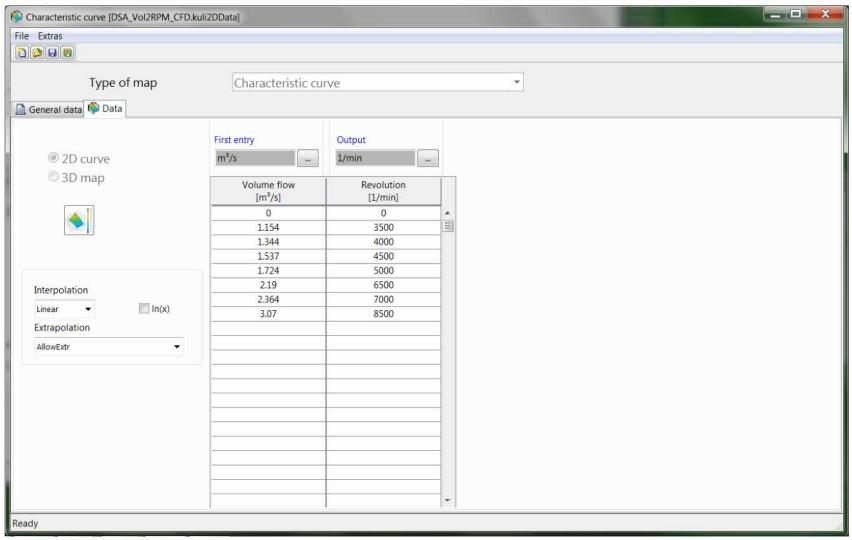
DSA\_Vol2kW\_CFD.kuli2DData



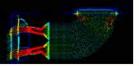


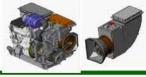
### **Kuli Drive Snake Air Flow - Output**



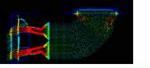


DSA\_Vol2RPM\_CFD.kuli2DData



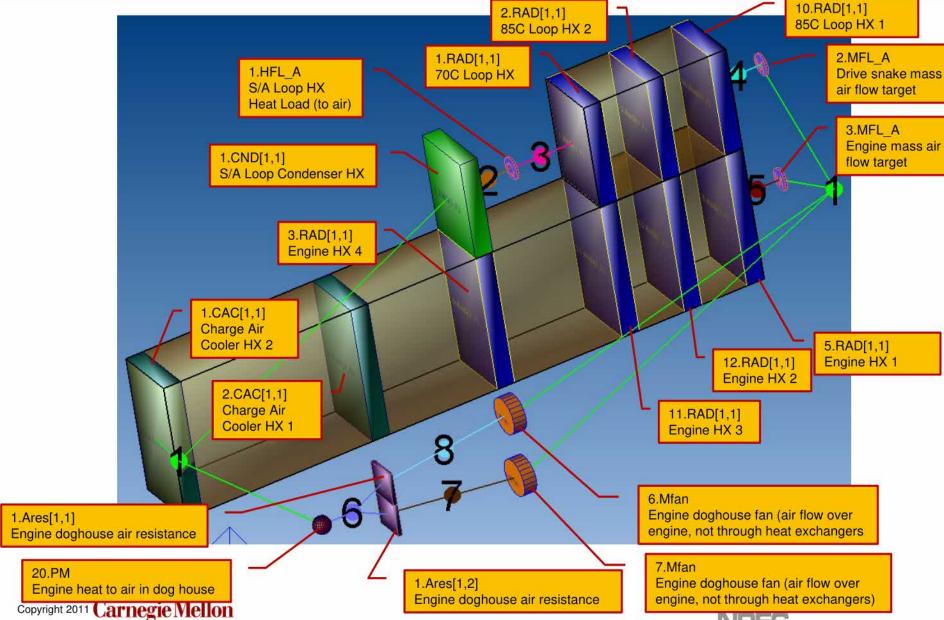


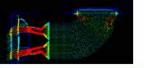
### Air side – Heat Exchanger Order



## XV KULI Model – 3D Air Path Details







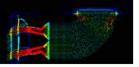
### XV KULI Model Overview -Air side components

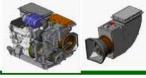




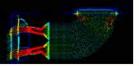
#### Air side components - locations and functions

ID	Width Diameter	Height [mm]	Depth [mm]	Pos x [mm]	Pos y [mm]	Pos z [mm]	Comments
Components							
1.Area resistance	150	300	20	200	-375	0	Backpressure inside engine compartment
1.Condenser	319	457	83	500	375	635	SA HVAC Condenser
2.Charge air cooler	319	635	83	0	375	0	CAC 2 Radiator
3.Charge air cooler	319	635	83	250	375	0	CAC1 Radiator
6.Mechanically driven fan	167	167	59	300	-300	0	Fan pulls ambient air into and through the engine compartment
7.Mechanically driven fan	167	167	59	300	-300	300	Fan pulls ambient air into and through the engine compartment
20.Point Mass	37.2	=	-	100	-300	150	Engine heat (other than exhaust or coolant) convecting to air in the engine compartment
2.Mass flow target (Air)	7 <u>-</u> 2	2.	2	1500	535	877	Drive snake air flow (represents mass flow rate pulled through drive snake by the fan)
3.Mass flow target (Air)	3=3	-	-	1500	535	318	Engine snake air flow (represents mass flow rate pulled through drive snake by the fan)
1.Heat flow source (Air)	370		-	600	535	877	SA HVAC loop heat to air - flows into 70C radiator
1.Radiator	319	483	83	750	375	635	70C Loop Radiator
10.Radiator	319	483	83	1250	375	635	85C Loop Radiator 1
11.Radiator	319	635	83	750	375	0	Engine Radiator 2
12.Radiator	319	635	83	1000	375	0	Engine radiator 3
2.Radiator	319	483	83	1000	375	635	85C Loop Radiator 2
3.Radiator	319	635	83	500	375	0	Engine radiator 4
5.Radiator	319	635	83	1250	375	0	Engine Radiator 1



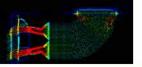


# Common Components – Used in more than one loop

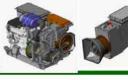


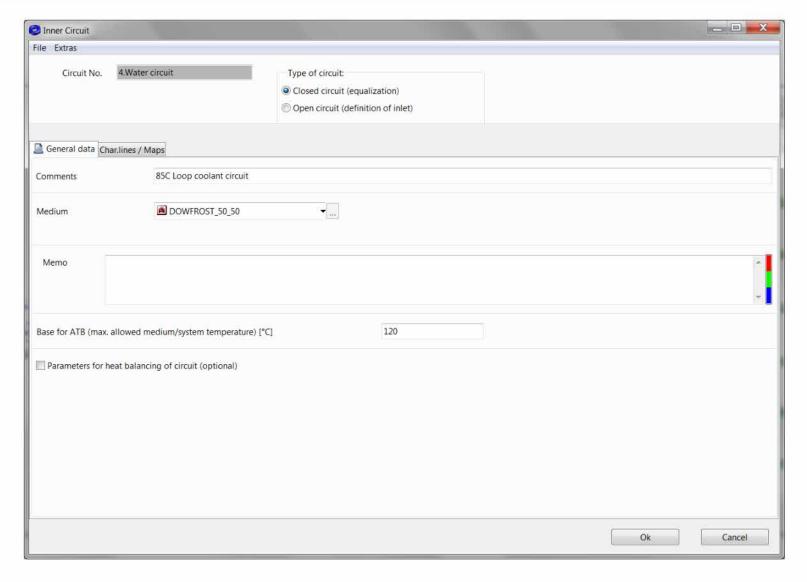


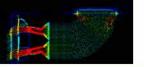
### **Working Fluids**



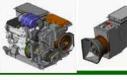
### EGW - 50/50

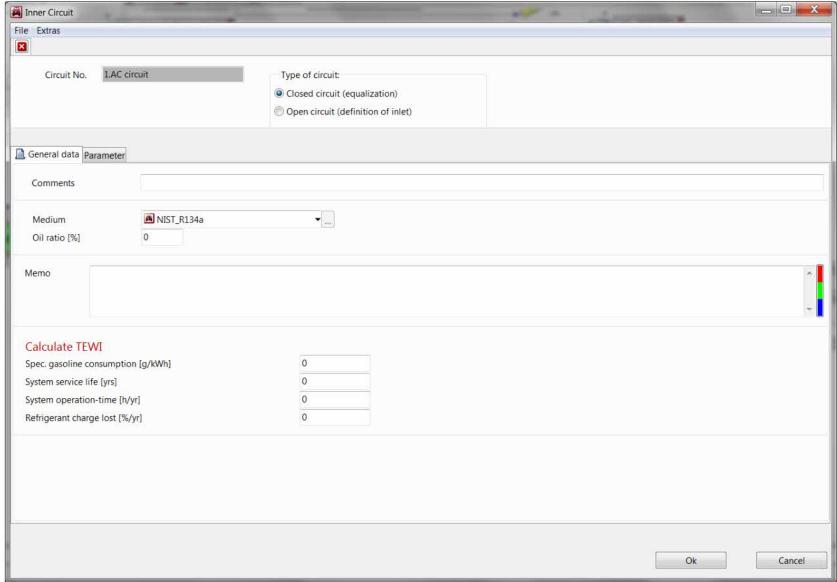


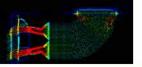




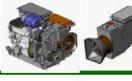
### **R134a Parameters**

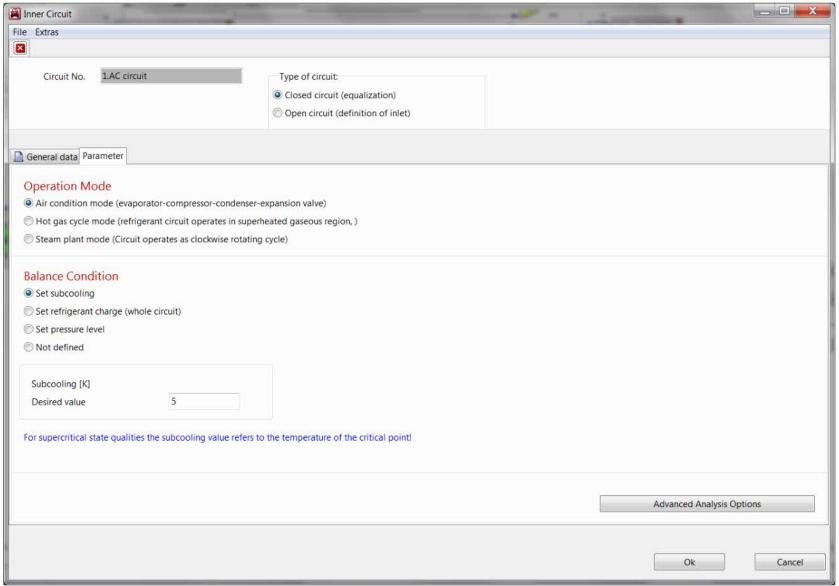


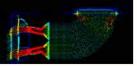




#### R134a Parameters

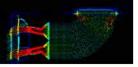




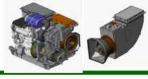


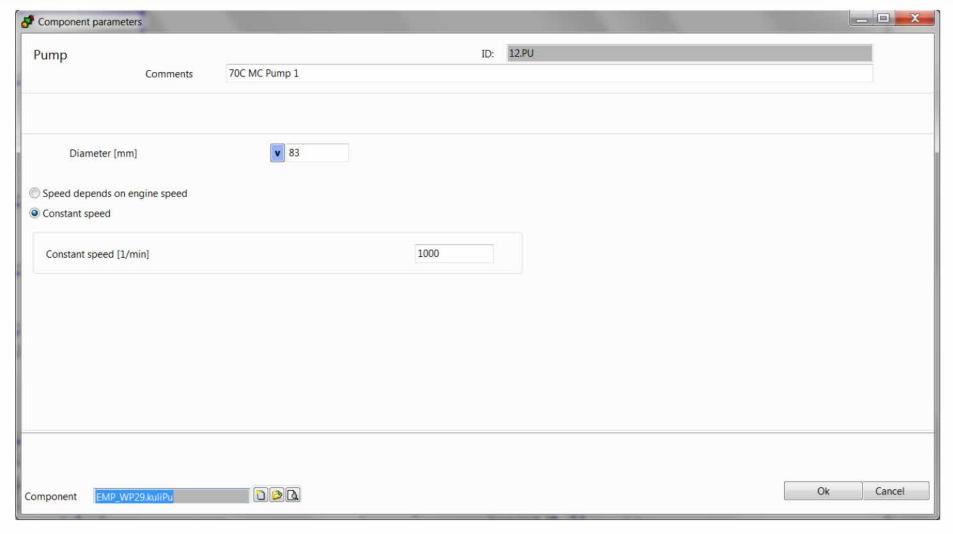


### **Pump**



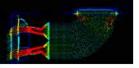
### **Electric Pump**



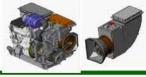


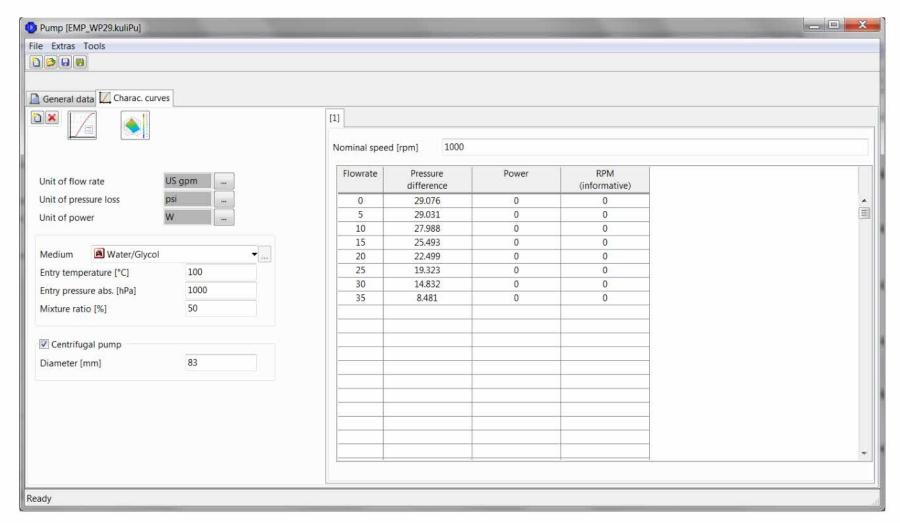
EMP\_WP29.kuliPu





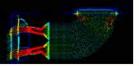
### **Electric Pump**

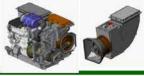




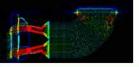
EMP\_WP29.kuliPu



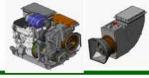


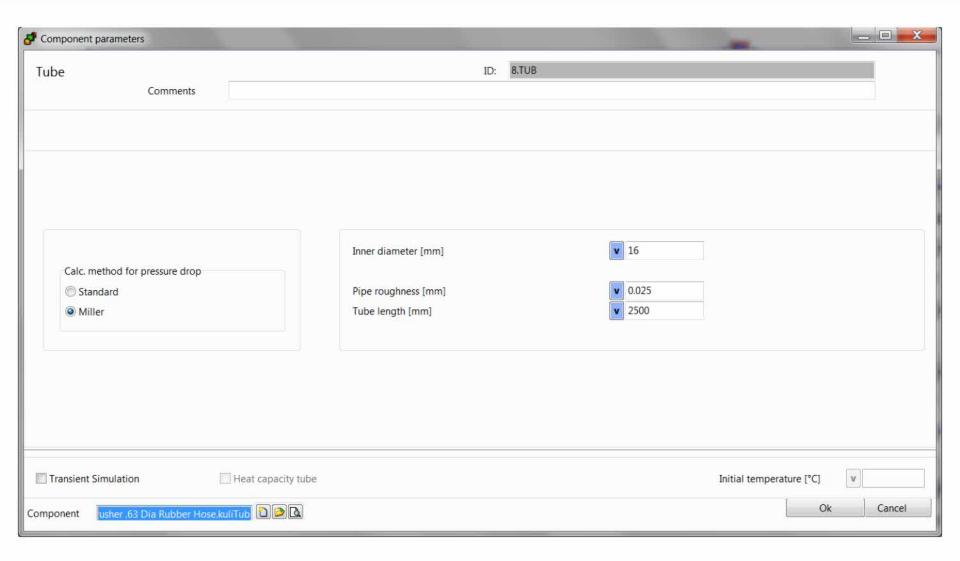


# Hoses, Tubes, Fittings

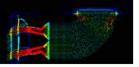


### 0.63" Rubber Hose



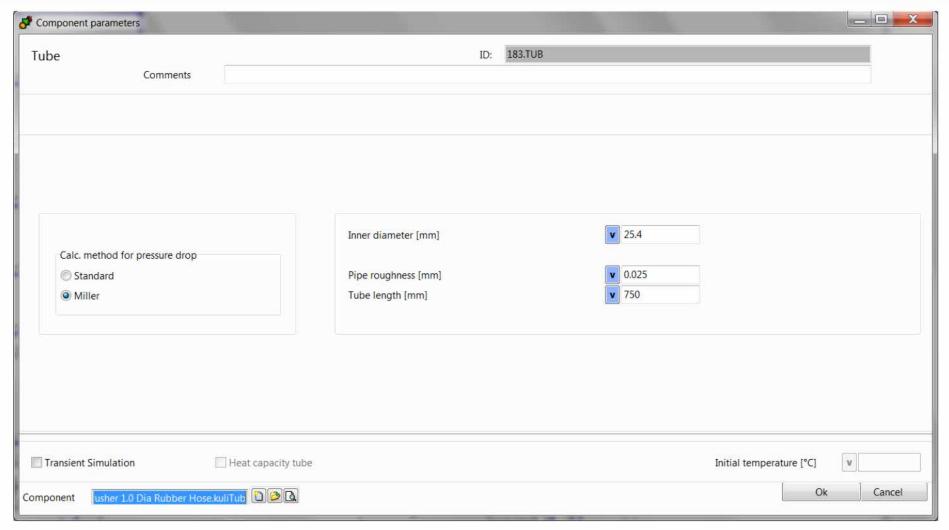


Crusher .63 Dia Rubber Hose.kuliTub

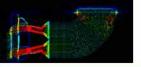


### 1" dia rubber hose

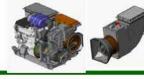


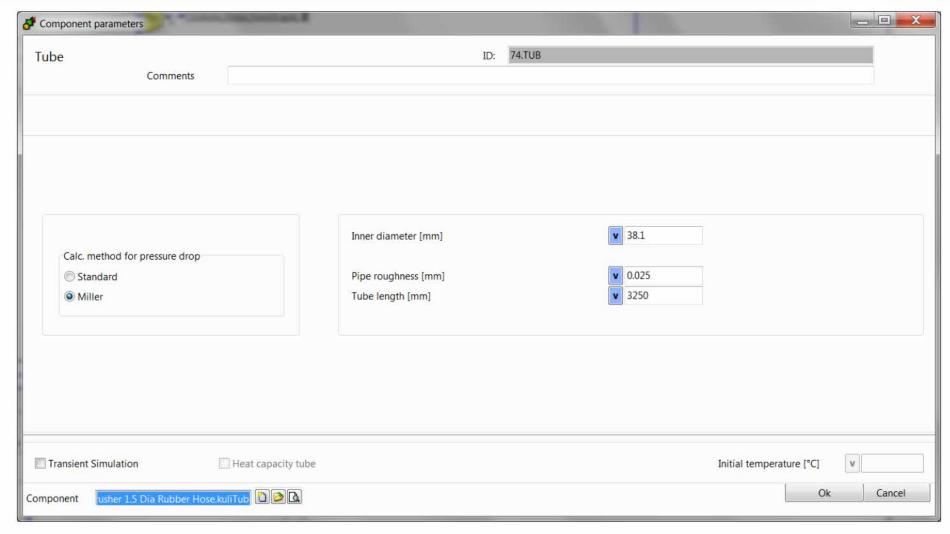


Crusher 1.0 Dia Rubber Hose.kuliTub



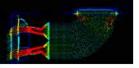
### 1.5" dia rubber hose



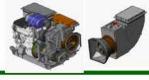


Crusher 1.5 Dia Rubber Hose.kuliTub

See 182. Tube for component file information and available COM I/O.

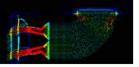


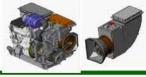
### **Motor 90° Fitting**



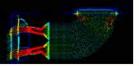
Bend  Comments	ID: 4.BNC	
Calc. method for pressure drop  Standard  Miller	Inner diameter [mm]  Pipe roughness [mm]  Angle of deflection [°]  Curvature radius [mm]	v 16 v 0.0063 v 90 v 9.5
☐ Transient Simulation ☐ Heat component ☐ Crusher Motor Inlet Fittin	apacity tube	Initial temperature [°C]  Ok  Cancel

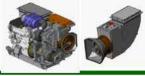
Crusher .63 Dia Rubber Hose.kuliTub

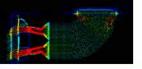




### **Heat Exchangers**



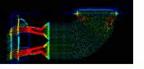




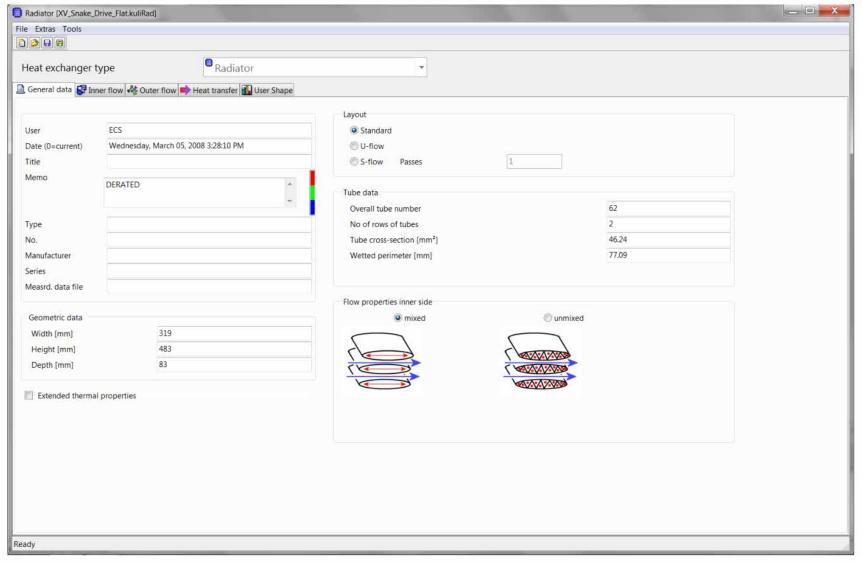


Component parameters	THE PERSON NAMED IN COLUMN 1		_ C _X
Radiator	ID: 2.RAD		
Comments 85C Lo	op Radiator 2		
Nidth [mm] 319 Height [mm]	483 Depth [mm] 83 X 1000 Y 375	Z 635	
Inner flow direction	-z (against z-direct.): Top right  ▼	Subdivision	automatic
		Division Width [mm]	Division eight [mm]
			The state of the s
Fauling factor [%]	<b>v</b> 0		
Change of dimensions when controlled via actuator			
Width	+y (in y-Direction) ▼		
Height	=z (in both directions) ▼		
Transient Simulation		Initial tempera	ture [°C]
M/ Code Diverting			Ok Cancel
pmponent XV_Snake_Drive_Flat.kuliRad			

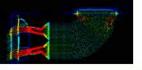


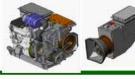


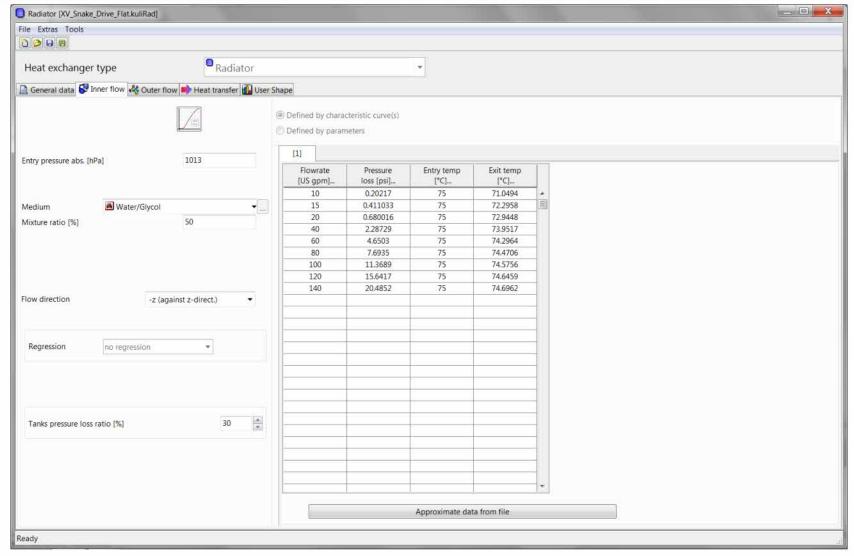




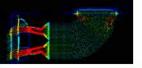


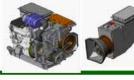


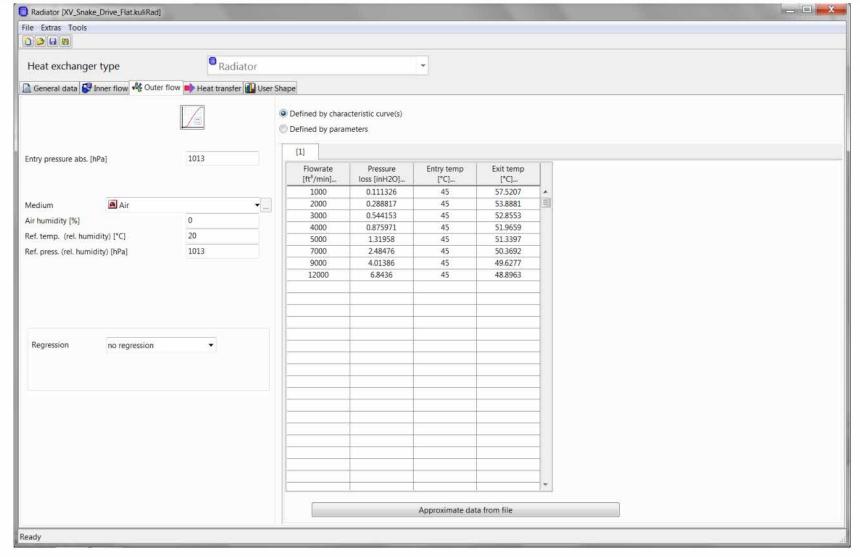


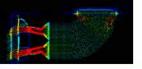


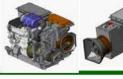


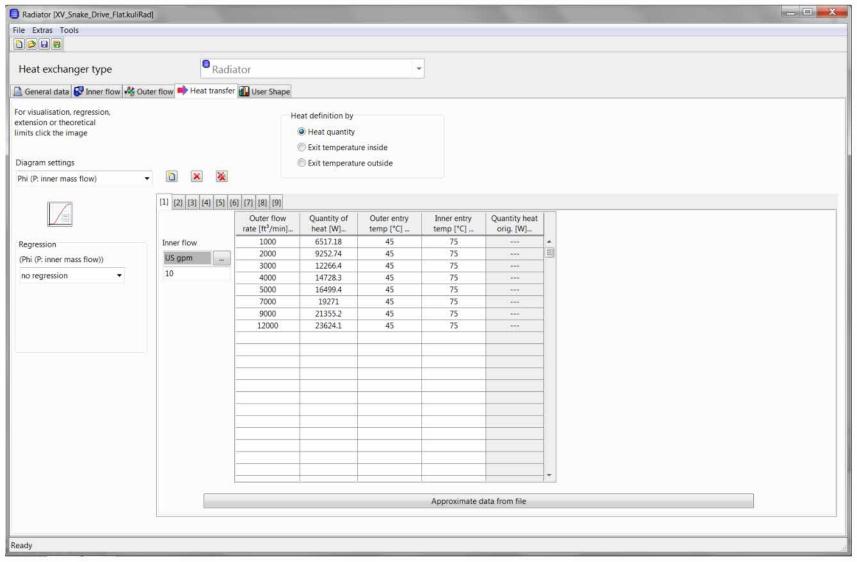




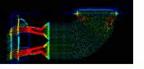


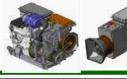


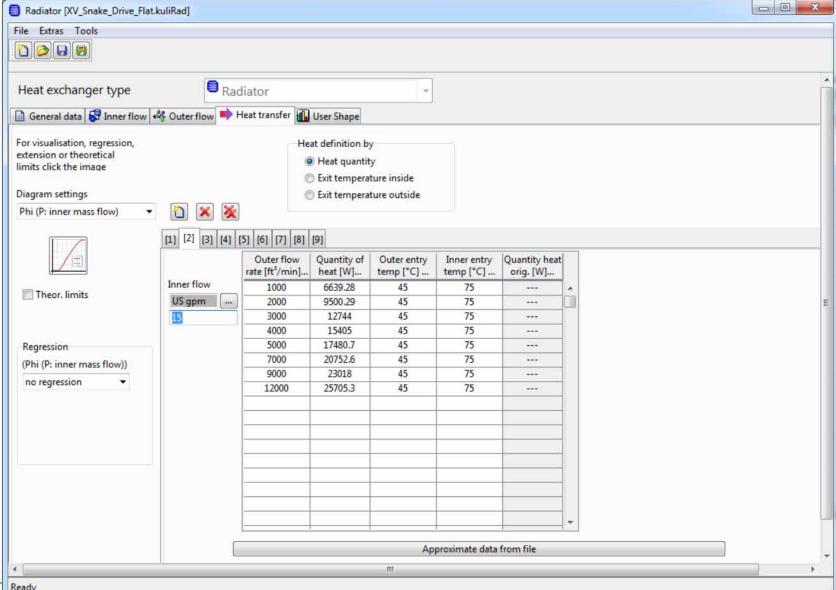






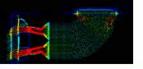




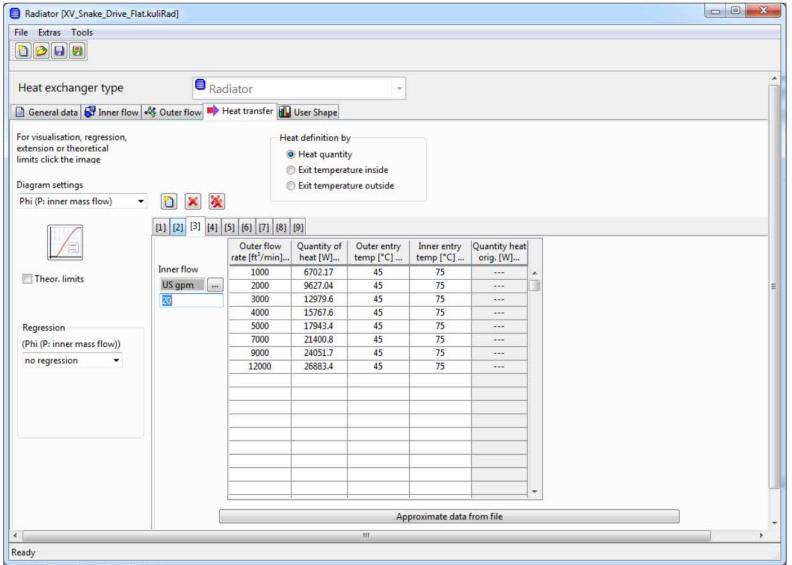


XV\_Snake\_

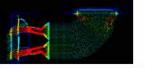
Copyright 2011 Carnegie Viellon

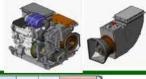


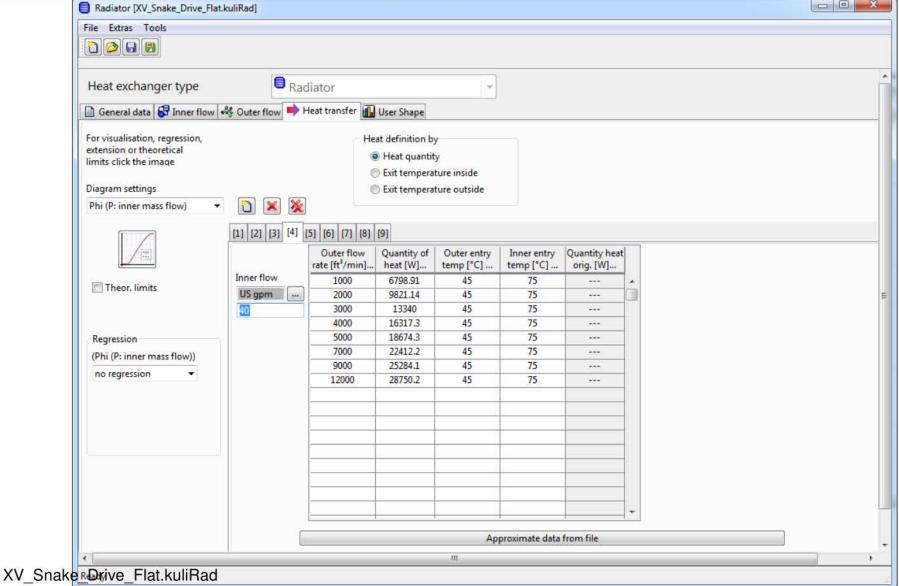




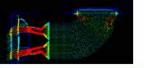


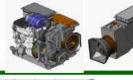


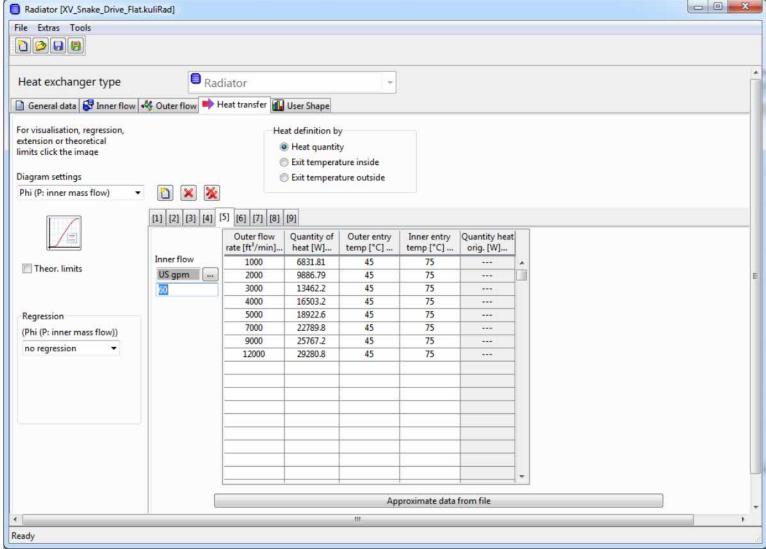




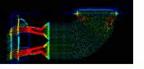
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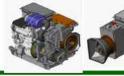


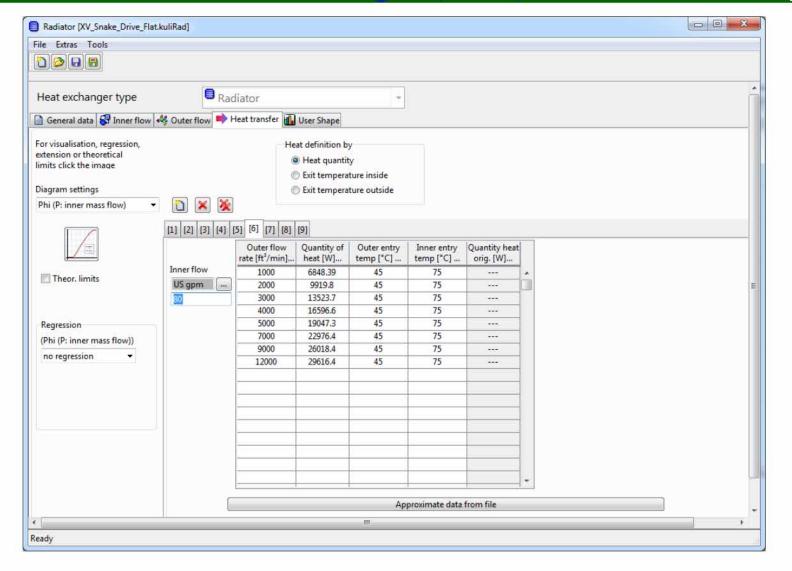




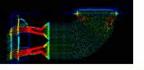




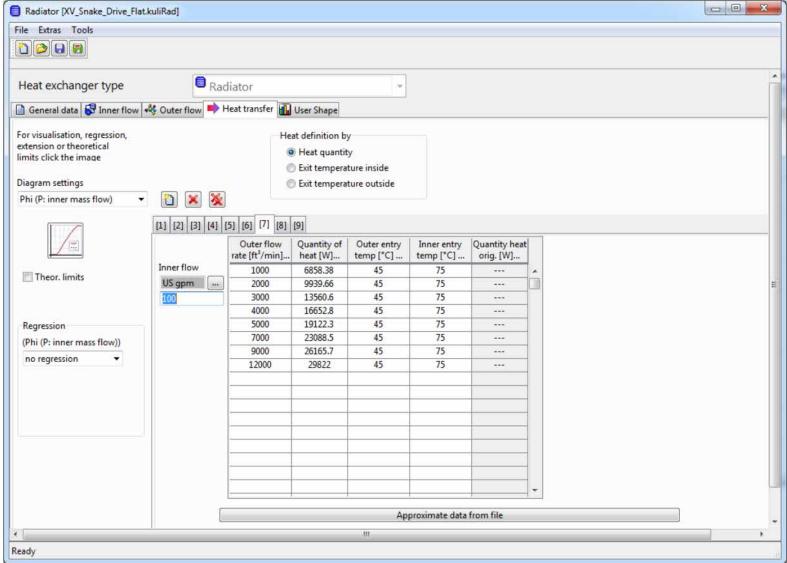






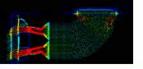




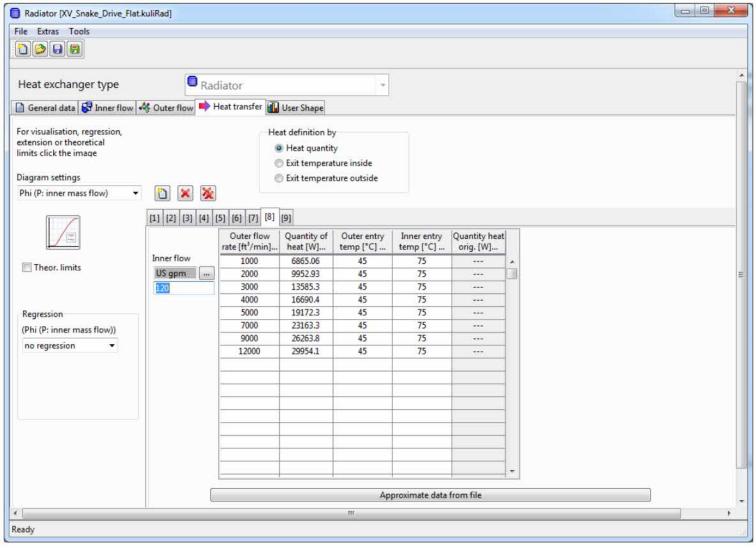


XV Snake Drive Flat.kuliRad

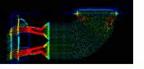




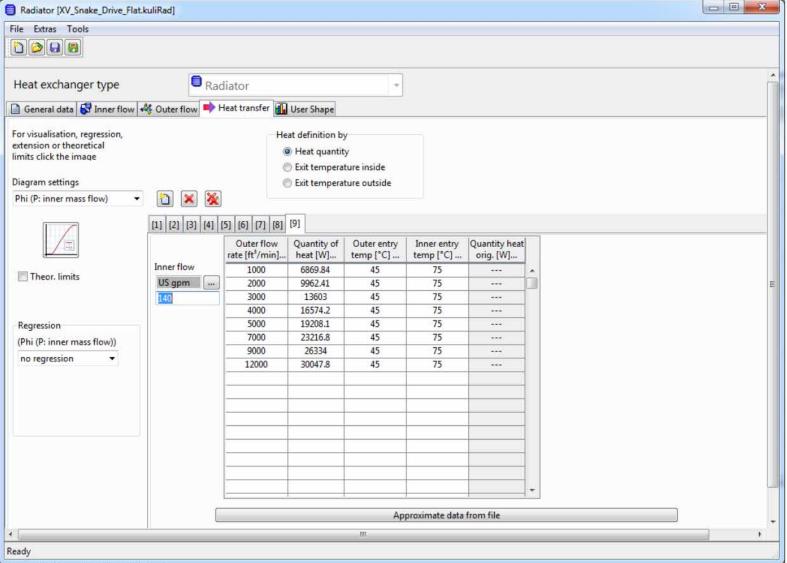






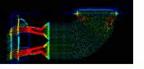


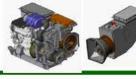


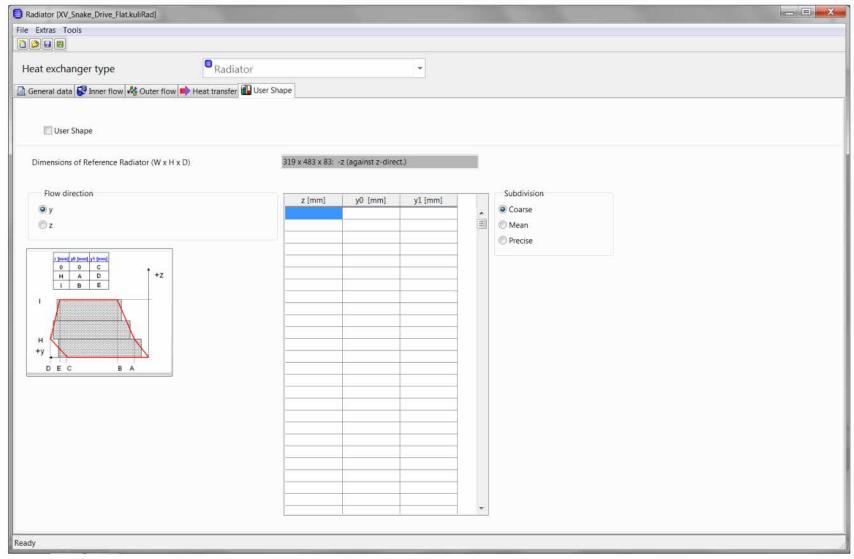


XV Snake Drive Flat.kuliRad











#### THERMAL MANAGEMENT OF THE EXPERIMENTAL VEHICLE (XV)

Disclaimer: Reference herein to any specific commercial company, product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the Department of the Army (DoA). The opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or the DoA, and shall not be used for advertising or product endorsement purposes.

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#### Overview

Thermal management was a critical item on the Experimental Vehicle (XV) development. Successful demonstration of key, high-power, mobility requirements at or near the objective ambient temperature of 45 C would be indicative of the viability of ground vehicles of XV's class in today's combat environments. Continuous, steady-state stressing cases are the most important drivers of thermal management system design. The commitment to this goal was evident as the XV thermal management design target never wavered from system that would support all mobility requirements at 45 C ambient with ballistic grills, even though full capability at 25 C without ballistic grills was the contractual requirement. A further testament was the inclusion of over a week's worth of high power testing at ambient conditions up to 45 C in the a temperature controlled chassis dynamometer test. In that, the XV vehicle successfully demonstrated its most thermally demanding mobility requirements at temperatures just shy of 45 C. Further, during mobility testing at an outdoor environment, where temperatures reached 43 C, the XV experienced no thermal faults after appropriate system maintenance procedures were adopted.

#### Design Challenges

Designing a thermal management system that would support all of the contractual mobility requirements and program objectives proved to be a significant challenge. Typical ground combat vehicle cooling system design hurdles, which were also common to XV include:

- High performance/mobility requires a significant amount of power, which produces significant heat
- Efficiently rejecting heat favors large unrestricted cooling air paths
- Military vehicles have limited volume available for cooling air paths, which must also be protected by ballistic grills
- Ballistic grills and small air path volumes restrict air flow and drive up required cooling fan power
- Higher ambient temperatures drive up required cooling fan power
- Available cooling fan power is finite and providing additional fan power produces additional heat

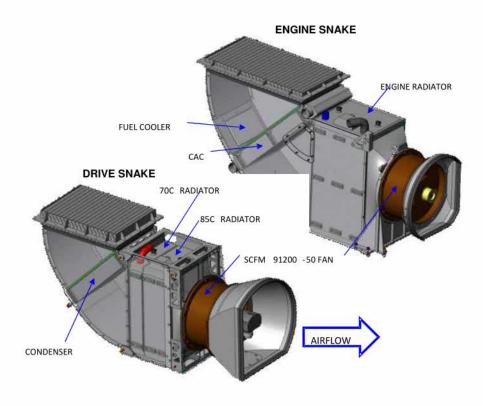
The result is that for a given vehicle with a finite power source, the available traction decreases as ambient temperature increases because the cooling fan requires additional power. In addition to this, several other factors challenged the designers of the XV thermal management system. They include:

- COTS electronics used for XV have lower maximum operating temperatures than their military grade counterparts
- Hybrid-Electric drive components (Motors/Generators and controllers) have lower maximum operating temperatures than purely mechanical drive system (Engine-Transmission)
- Hybrid-Electric drive trains reject more heat than a purely mechanical drive trains
- Component coolant temperature requirements vary significantly (10 C for batteries and electronics to 95 C for the engine)
- Over 30 components or enclosures required cooling complicating system design and integration
- Small order volumes limited the number of interested suppliers for custom components (Fans, Radiators, etc.)

To tackle these design challenges and produce a robust research platform that also demonstrated the combat viability of an XV-like vehicle, a variety of cooling topologies incorporating various features and characteristics were considered. Two of the key features traded include:

- Number of liquid cooling circuits (coolant temperatures)
  - More cooling loops yield maximum efficiency (low cooling power consumption) over a range of operating conditions
  - Less cooling loops for simpler design and integration
- Number of cooling air paths and/or fans
  - Multiple cooling air paths/fans yield maximum efficiency over a range of operating conditions; especially engine off/battery only ("silent" mobility)
  - Single cooling air path/fan for simpler design and integration

Candidate topologies were evaluated against a variety of weighted metrics to select the best thermal management approach. The two finalists were the Dual Snake (two air paths each with their own fan) and the Traditional (single air path with one or more fans). Each of these candidates contained five main cooling circuits. In the end, the Dual Snake topology was selected for its efficiency and versatility. It is described in the figures and tables below.



XV Engine and Drive Snake

AIRPATH 1 - Po	rt Side (Drive Snake)	AIRPATH 2 - Starboard Side (Engine Snake)		
Heat Exchanger	Design Heat Rejection and Coolant Spec	Heat Exchanger	Design Heat Rejection and Coolant Spec 60 C (Air) 120 kW - 180 LPM @ 95 C (Coolant)	
A/C System Condenser (Batteries and Misc Electronics)	10 kW - 40 LPM @ 10 C (Chilled Coolant)	Single Pass Charge Air Cooler		
Single Pass Radiator (HV Electronics and Aux Motors/Generators)	12 kW - 225 LPM @ 70 C	Quad Pass Radiator (Engine and Brake Shunt Resistor)		
Dual Pass Radiator (Wheel Motors and Main Generator)	35 kW - 85 LPM @ 85 C			
Fan Airflow Estimate	Fan Power	Fan Airflow Estimate	Fan Power	
5100 SCFM @ 6100 RPM	10 kW Electrical @ 6100 RPM (Electric Motor Driven)	8600 SCFM @ 10,000 RPM	43 kW Mechanical @ 10,000 RPM (Electric Motor or Engine Drive; both via Belt)	

#### Description

The air path architecture adopted for XV was a dual air path configuration termed the Dual Snake. It consists of two independent air paths (the Engine and Drive Snake) each with their own cooling fan. The Engine Snake provided engine cooling and the Drive Snake provided cooling for all electronic, electrical and hybrid-electric drive components. This architecture provided tremendous benefits including:

- High efficiency (low cooling power consumption per rate of heat rejection) over a range of operating conditions
- Engine-off/Silent-mobility benefits including
  - Low power consumption
  - Low fan noise

The XV thermal management system uses a 50/50 mixture of Ethylene Glycol and Water (EGW) as the primary means of distributing cooling throughout the vehicle. Testing with a 50/50 Propylene Glycol and water mixture

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(PGW) was carried out in the SIL and the vehicle is compatible with both coolants. There are four different EGW cooling loops present on the vehicle that provide cooling to over 30 different components and enclosures. All components/enclosures are plumbed in parallel with the exception of the Brake Shunt Resistor and Engine which are plumbed in series. The engine's fuel and charge air are cooled directly by air without an EGW intermediary fluid. A description of the vehicle cooling loops, their capabilities and the components they cool is included in the table below.

DESCRIPT	TON OF COOLE	D COMPONENTS			
DRIVE SNAKE		ENGINER SNAKE			
SUB-AMBIENT LOOP	FUEL COOLER				
10 kiwi MAX - 40 LPM WGW MAX at 10 C NOMINAL	60 c MAX FUEL TEMP				
COMPONENT	QUANTITY	COMPONENT	QUANTITY		
LV Electronics Enclosure	1				
HV Electronics Enclosure	1				
Controller w/ Cold Plate	2	Engine Fuel (DF2 or JP8)	1		
Turret	1				
Battery Enclosure	2				
70C LOOP	CHARGE AIR COOLER				
12 kW MAX - 225 LPM EGW MAX at 70 C N	60 C MAX AIR TEMP				
COMPONENT	QUANTITY	COMPONENT	QUANTITY		
Wheel Motor Controller	6		1		
Generator Controller	1				
Brake Chopper Shunt Controller	2				
350 V - 750 V Convertor	2	PERSONAL AND COLUMN			
350 V Motor/Generator	1	Engine Charge Air	1		
Generator Controller	1				
Drive Snake Fan Motor	1				
350 V to 12/28 V Convertor	3				
85 C LOOP		ENGINE LOOP			
35 kW MAX - 85 LPM EGW MAX at 85 C N	1AX	20 KW MAX (Engine Only) - 180 LPM EGW	MAX at 95 CT		
COMPONENT	QUANTITY	COMPONENT	QUANTITY		
Wheel Motor	6	Engine	1		
750 V Generator	1	Brake Shunt Resistor (40 kW Max Expected)	1		

The heat load, coolant flow rate and temperatures specified in this table were stated as follows:

#### SUB-AMBIENT LOOP

- Heat load is maximum anticipated (max vehicle load at 45 C ambient temperature with solar load) and was also the system's design capacity
- Coolant flow rate and temperature are the values expected to maintain all sub-ambient components at acceptable temperatures under worst case conditions; this was also the system's design performance

#### 70 C LOOP

- Heat load is the maximum anticipated (80 kph @ 45 C) and was also the system's design capacity after fouling margin
- Coolant flow rate is the sum of the prescribed coolant flow rates for each of the components and was also the system's design flow rate
- Coolant temperature is the maximum coolant temperature prescribed for each of the components and was also the system's design temperature after fouling margin

#### 85 C LOOP

- Heat load is the maximum anticipated (80 kph @ 45 C) and was also the system's design capacity after fouling margin
- Coolant flow rate is the sum of the prescribed coolant flow rates for each of the components and was also the systems design flow rate

 Coolant temperature is the maximum coolant temperature prescribed for each of the components and was also the system's design temperature after fouling margin

#### **FUEL COOLER**

- Maximum fuel temperature before the engine will begin to limit power and design temperature

#### CHARGE AIR COOLER

 Maximum charge air temperature before the engine will begin to limit power and design temperature after fouling margin

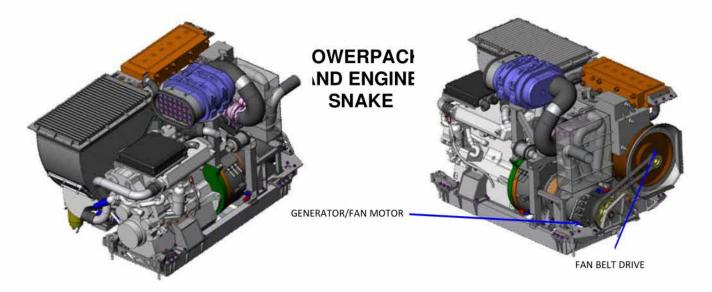
#### **ENGINE LOOP**

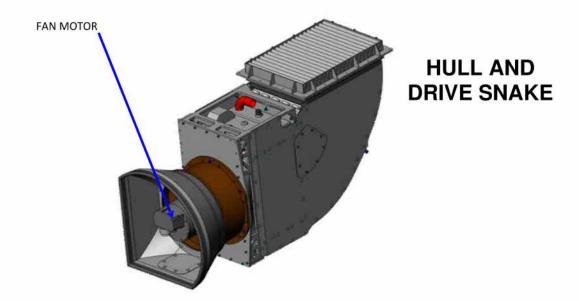
- Maximum expected engine heat rejection plus 20% margin over test data (added in case hot engine bay conditions led to additional engine to coolant heat rejection) and was also the system's design capacity after fouling margin
- Maximum measured engine coolant flow rate
- Prescribed shunt coolant inlet temperature
- Engine coolant inlet temperature predicted to achieve adequate cooling at maximum engine output power (the engine will limit power if the coolant outlet temperature reaches 105 C) after fouling margin and 20% additional engine to coolant heat rejection

Note that all of the heat rates mentioned in this table are the maximum continuous heat rates expected based on test or manufacturers data. Intermittent heat rates may exceed these values, but were not a significant factor in thermal management system design.

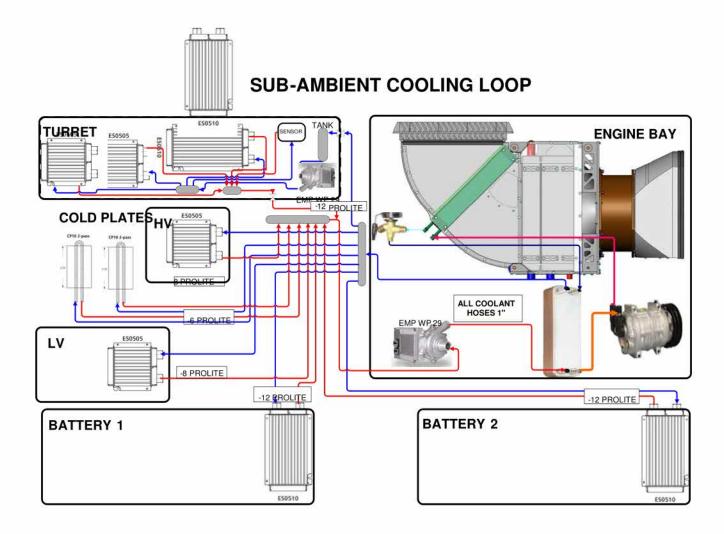
#### Physical System Description

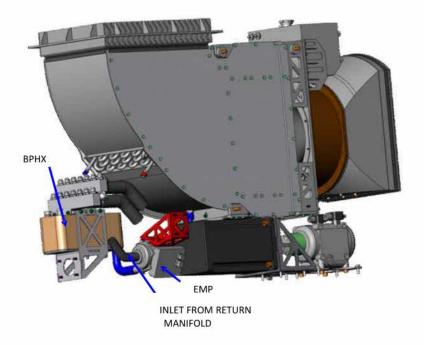
The Engine and Drive Snakes are located on either side of the engine. The Engine Snake is an integral part of the Power Pack while the Drive Snake mounts to the hull of the vehicle.

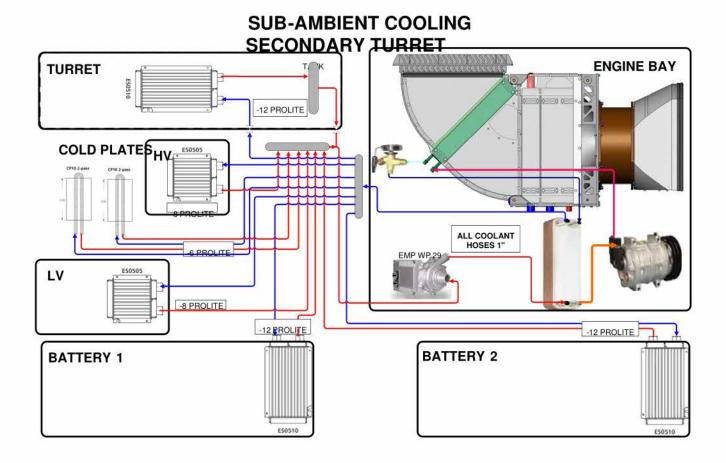


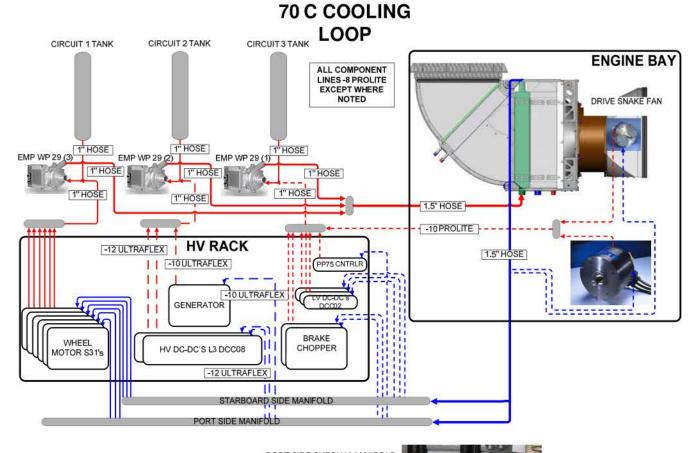


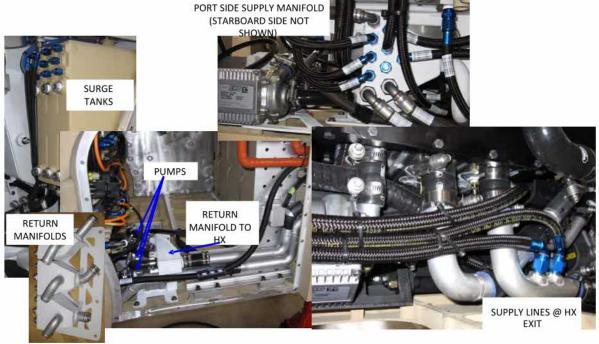
The integration of the Drive and Engine Snakes with the rest of the cooling system is shown in the schematics and images below. Many line sizes and component model numbers are noted on these schematics. Note that all components receiving EGW cooling are plumbed in parallel with the exception of the Engine and Brake Shunt Resistor.



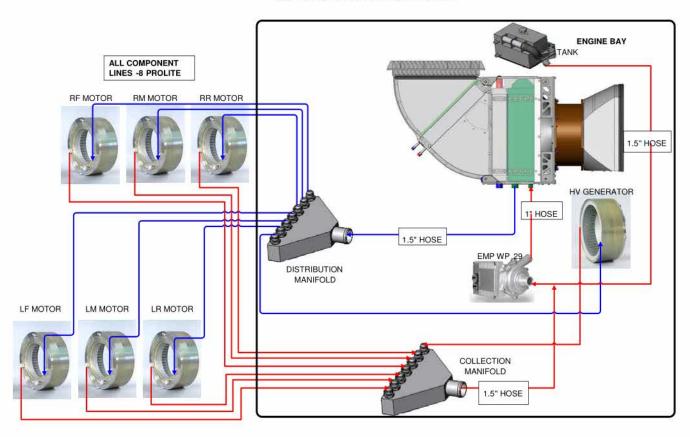


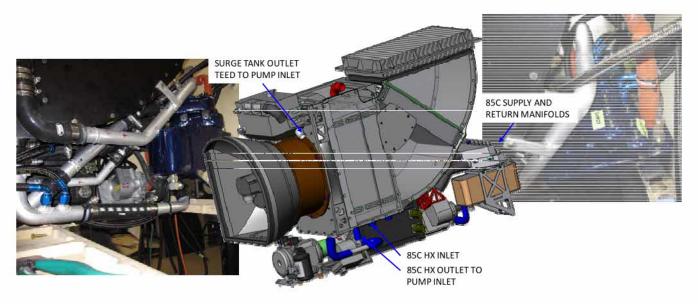




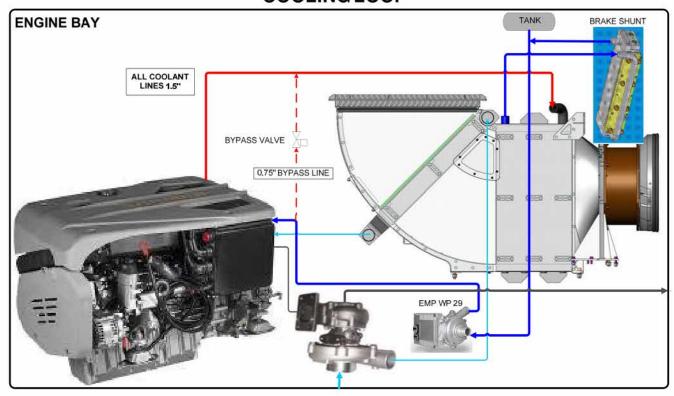


### **85 C COOLING LOOP**





### ENGINE COOLING LOOP



#### Significant Design Tools and Data

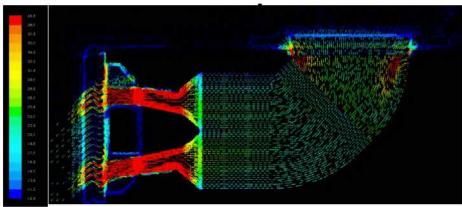
#### **KULI AND SIMULINK**

KULI is a one-dimensional thermal-fluid simulation software package with a block-diagram style GUI (<a href="http://www.kuli.at/">http://www.kuli.at/</a>). For the XV program it was used to rapidly model candidate cooling topologies, simulate their performance and investigate the effects of system modifications while fine-tuning the design. MATLAB-Simulink was used to model vehicle heat rejection from various components and this data was fed into KULI for thermal-fluid (cooling system performance) simulation. The results from KULI were component and fluid temperatures, air and coolant flow rates and required cooling fan powers.

#### **FLUENT CFD**

Fluent CFD models of candidate cooling air paths were developed and exercised by ThermalAnalytics. These simulations provided more accurate estimates of cooling fan power and heat exchanger performance than the KULI models. Data was routinely passed back and forth (in an offline fashion) between KULI and Fluent for model/simulation improvement.

#### DRIVE SNAKE VELOCITY VECTORS (M/S)



#### SUPPLIER AND TEST DATA

Various data sources were used to support the simulations used to design and fine-tune the XV cooling system. Supplier data such as pump and fan curves and motor and controller efficiency data was supplemented with test data. This all served to generate more accurate cooling system performance estimates.

#### **FULL VEHICLE THERMAL MODEL**

ThermalAnalytics developed a full vehicle thermal model using their own software packages to help predict temperatures and heat rejection rates inside the vehicle. This model included solar loading. The results were estimates of the heat that would infiltrate the sub-ambient enclosures (and in turn must be carried away by the sub-ambient cooling system) and the effect adding insulation to these enclosures would have. This model was also able to predict the total solar heat load on the vehicle, temperatures inside the turret where sensitive electronics would be housed and the temperature inside the engine bay.

#### **Performance Summary**

XV testing on a chassis dynamometer was the most valuable indicator of the XV thermal management system's ability to meet its cooling objectives under the harshest of conditions. Subsequent testing in the field provided valuable data regarding the system's ability to provide adequate cooling under the most extreme field conditions the vehicle is expected to see in its lifetime. These included high ambient temperatures, solar loading and extreme dust. Testing was also valuable to determine baseline performance of the system when compared to design calculations/simulations and actual vehicle performance. The PowerPack cooling tested at 45+C temperatures. At no time was field testing impacted by the performance of the XV thermal management system. Any maneuver that had the potential to cause a component to overheat was tested. A fouled or otherwise degraded system would support full capability at approximately 35 C or greater depending on the level of fouling/degradation.

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#### Section 18-23 - ADDITIONS TO DD FORM 1155

ITEM NO.	SUPPLIES/SERVICES	QUANTITY	UNIT	UNIT PRICE	AMOUNT
0001		1		\$94,999.00	\$94,999.00

META Program Component Model Library

FFP

The Contractor shall support DARPA/TTO's META program in accordance with

the Statement of Work - Attachment 1, dated July 18, 2011.

FOB: Destination

NET AMT \$94,999.00

TTEM NO. SUPPLIES/SERVICES QUANTITY UNIT UNIT PRICE AMOUNT 000101 \$0.00

Funding for CLIN 0001

FFP

Funding for CLIN 0001 FOB: Destination AO No. 7925/00

NET AMT \$0.00

ACRN AA \$94,999.00

#### INSPECTION AND ACCEPTANCE TERMS

#### Supplies/services will be inspected/accepted at:

CLIN	INSPECT AT	INSPECT BY	ACCEPT AT	ACCEPT BY
0001	Destination	Government	Destination	Government
000101	Destination	Government	Destination	Government

#### DELIVERY INFORMATION

CLIN	DELIVERY DATE	QUANTITY	SHIP TO ADDRESS	UIC
0001	POP 02-SEP-2011 TO 03-JAN-2012	N/A	DARPA PAUL EREMENKO ATTN: TACTICAL TECHNOLOGY OFFI 3701 NORTH FAIRFAX DRIVE ARLINGTON VA 22203-1714 571-218-4889 FOB: Destination	HR0011
000101	N/A	N/A	N/A	N/A

# ACCOUNTING AND APPROPRIATION DATA

AA: 9710400 1320 7925 PIM30 2525 DPAC 1 5362 S12136 62303E

AMOUNT: \$94,999.00

#### CLAUSES INCORPORATED BY FULL TEXT

## I. INSPECTION AND ACCEPTANCE

Inspection and acceptance shall be made at destination by the receiving activity.

#### 2. PERFORMANCE

The term of the Purchase Order shall be from September 2, 2011 through January 3, 2011.

#### 3. PURCHASE ORDER ADMINISTRATIVE DATA

- (a) Invoices for goods received or services rendered under this purchase order shall be submitted electronically through Wide Area Work Flow Receipt and Acceptance (WAWF):
  - (1) Vendors that have never used WAWF shall follow the directions in the <u>WAWF Vendor Getting Started Guide</u> available at the following website:
  - http://www.dfas.mil/contractorpay/electronicconumerce/wideareaworkflow.html. This website also contains

links for Vendor training and practice. Additional support can be obtained by calling WAWF Customer Service at 866-618-5988.

- (2) Back up documentation (such as timesheets, monthly status reports, etc.) can be included and attached to the invoice in WAWF. Attachments should be in PDF format, but Attachments created in any Microsoft Office product may be attached. Total limit for the size of files per invoice is 5 megabytes.
- (b) The following information, regarding invoice routing DODAAC's, must be entered for completion of the invoice in WAWF:

WAWF Invoice Type:	2-in-1	i
Issuing Office DoDAAC	HR0011	
Admin Offfice DoDAAC	HR0011	
Service Acceptor DoDAAC	HR0011, extension 08	
Paying Office DoDAAC	HQ0339	

(c) For each invoice/cost voucher submitted for payment, the contractor shall also e-mail the WAWF automated invoice notice directly to the following points of contact:

Name	E-mail	Phone	Role
Chris Glista	jehristopher.glista@darpa.mil	(571) 218-4405	Contracting Officer
Paul Eremenko	paul.eremenko@darpa.mil	(571) 218-4889	META Program Manager

(d) Travel. All travel requests, other than local travel, shall be approved in advance by the Contracting Officer. All travel costs are subject to Public Law 99-234, FAR 31.205-46 (Deviation) and the Joint Travel Regulations.

# 4. PURCHASE ORDER CLAUSES

This Purchase Order incorporates the following clauses by reference, with the same force and effect as if they were given in full text.

#### CLAUSES INCORPORATED BY REFERENCE

# FEDERAL ACQUISITION REGULATION (FAR) (48 CFR CHAPTER 1) CLAUSES:

52.204-7	Central Contractor Registration	OCT 2003
52,213-2	Invoices	APR 1984
52.213-4	Terms and Conditions - Simplified Acquisitions (Other Than Commercial Items)	APR 2005
52.232-25	Prompt Payment	OCT 2003
52.232-33	Payment by Electronic Funds Transfer—Central Contractor Registration	OCT 2003
52.242-15	Stop-Work Order	AUG 1989
52.243-1 Alt V	Changes Fixed-Price (Aug 1987) - Alternate V	APR 1984

The full text of a FAR clause may be accessed electronically at: http://www.arnet.gov/far/.

DEPARTMENT OF DEFENSE FAR SUPPLEMENT (DFARS) (48 CFR CHAPTER 2) CLAUSES:

252.204-7004	Central Contractor Registration (52.204-7) Alternate A	NOV 2003
252.204-7005	Oral Attestation of Security Responsibilities	NOV 2001
252.232-7003	Electronic Submission of Payment Requests	JAN 2004
252.235-7010	Acknowledgment Of Support and Disclaimer	MAY 1995
252.243-7001	Pricing of Contract Modifications	DEC 1991

The full text of a DFARS clause may be accessed electronically at http://www.acq.osd.mil/dpap/dars/dfars/.

#### CLAUSES INCORPORATED BY FULL TEXT

#### 52.213-4 -- Terms and Conditions -- Simplified Acquisitions (Other Than Commercial Items) (May 2011)

- (a) The Contractor shall comply with the following Federal Acquisition Regulation (FAR) clauses that are incorporated by reference:
  - (1) The clauses listed below implement provisions of law or Executive order:
    - (i) 52,222-3, Convict Labor (June 2003) (E.O. 11755).
    - (ii) 52,222-21, Prohibition of Segregated Facilities (Feb 1999) (E.O. 11246).
    - (iii) 52,222-26, Equal Opportunity (Mar 2007) (E.O. 11246).
    - (iv) 52,222-50, Combating Trafficking in Persons (Feb 2009) (22 U.S.C. 7104(g)).
    - (v) 52,225-13, Restrictions on Certain Foreign Purchases (Jun 2008) (E.o.s, proclamations, and statutes administered by the Office of Foreign Assets Control of the Department of the Treasury).
    - (vi) 52.233-3, Protest After Award (Aug 1996) (31 U.S.C. 3553).
    - (vii) 52.233-4, Applicable Law for Breach of Contract Claim (Oct 2004) (Pub. L. 108-77, 108-78).
  - (2) Listed below are additional clauses that apply:
    - (i) 52.204-10, Reporting Executive Compensation and First-Tier Subcontract Awards (Jul 2010) (Pub. 1., 109) (31 U.S.C. 6101 note).
    - (ii) 52.232-1, Payments (Apr 1984).
    - (iii) 52.232-8, Discounts for Prompt Payment (Feb 2002).
    - (iv) 52.232-11, Extras (Apr 1984).
    - (v) 52.232-25, Prompt Payment (Oct 2008).
    - (vi) 52.233-1, Disputes (July 2002).
    - (vii) 52.244-6, Subcontracts for Commercial Items (Jan 2011).
    - (viii) 52,253-1, Computer Generated Forms (Jan 1991).
- (b) The Contractor shall comply with the following FAR clauses, incorporated by reference, unless the circumstances do not apply:

- (1) The clauses listed below implement provisions of law or Executive order:
  - (i) 52.222-19, Child Labor—Cooperation with Authorities and Remedies (Jul 2010) (E.O. 13126).(Applies to contracts for supplies exceeding the micro-purchase threshold.)
  - (ii) 52.222-20, Walsh-Healey Public Contracts Act (Oct 2010) (41 U.S.C. 35-45) (Applies to supply contracts over \$15,000 in the United States, Puerto Rico, or the U.S. Virgin Islands).
  - (iii) 52.222-35, Equal Opportunity for Veterans (Sep 2010) (38 U.S.C. 4212) (Applies to contracts of \$100,000 or more).
  - (iv) 52.222-36, Affirmative Action for Workers with Disabilities (Oct 2010) (29 U.S.C. 793) (Applies to contracts over \$15,000, unless the work is to be performed outside the United States by employees recruited outside the United States.) (For purposes of this clause, *United States* includes the 50 States, the District of Columbia, Puerto Rico, the Northern Mariana Islands, American Samoa, Guam, the U.S. Virgin Islands, and Wake Island.)
  - (v) 52.222-37, Employment Reports on Veterans (Sep 2010) (38 U.S.C. 4212) (Applies to contracts of \$100,000 or more).
  - (vi) 52.223-5, Pollution Prevention and Right-to-Know Information (May 2011) (E.O. 13423) (Applies to services performed on Federal facilities).
  - (vii) 52.223-15, Energy Efficiency in Energy-Consuming Products (Dec 2007) (42 U.S.C. 8259b) (Unless exempt pursuant to 23.204, applies to contracts when energy-consuming products listed in the ENERGY STAR® Program or Federal Energy Management Program (FEMP) will be—
    - (A) Delivered;
    - (B) Acquired by the Contractor for use in performing services at a Federally-controlled facility;
    - (C) Furnished by the Contractor for use by the Government; or
    - (D) Specified in the design of a building or work, or incorporated during its construction, renovation, or maintenance.)
  - (viii) 52.225-1, Buy American Act—Supplies (Feb 2009) (41 U.S.C. 10a-10d) (Applies to contracts for supplies, and to contracts for services involving the furnishing of supplies, for use within the United States or its outlying areas, if the value of the supply contract or supply portion of a service contract exceeds the micro-purchase threshold and the acquisition—
    - (A) Is set aside for small business concerns; or
    - (B) Cannot be set aside for small business concerns (see 19.502-2), and does not exceed \$25,000.)
  - (ix) 52.232-33, Payment by Electronic Funds Transfer—Central Contractor Registration (Oct 2003). (Applies when the payment will be made by electronic funds transfer (EFT) and the payment office uses the Central Contractor Registration (CCR) database as its source of EFT information.)

- (x) 52.232-34, Payment by Electronic Funds Transfer—Other than Central Contractor Registration (May 1999). (Applies when the payment will be made by EFT and the payment office does not use the CCR database as its source of EFT information.)
  - (xi) 52.247-64 Preference for Privately Owned U.S.-Flag Commercial Vessels (Feb 2006) (46 U.S.C. App. 1241). (Applies to supplies transported by ocean vessels (except for the types of subcontracts listed at 47.504(d).)
- (2) Listed below are additional clauses that may apply:
  - (i) 52.209-6, Protecting the Government's Interest When Subcontracting with Contractors Debarred, Suspended, or Proposed for Debarment (Dec 2010) (Applies to contracts over \$30,000). (Not applicable to subcontracts for the acquisition of commercially available off-the-shelf items).
  - (ii) 52.211-17, Delivery of Excess Quantities (Sep 1989) (Applies to fixed-price supplies).
  - (iii) 52.226-6, Promoting Excess Food Donation to Nonprofit Organizations. (Mar 2009) (Pub. L. 110 247) (Applies to contracts greater than \$25,000 that provide for the provision, the service, or the sale of food in the United states.)
  - (iv) 52.247-29, F.o.b. Origin (Feb 2006) (Applies to supplies if delivery is f.o.b. origin).
  - (v) 52.247-34, F.o.b. Destination (Nov 1991) (Applies to supplies if delivery is f.o.b. destination).
- (c) FAR 52.252-2, Clauses Incorporated by Reference (Feb 1998). This contract incorporates one or more clauses by

reference, with the same force and effect as if they were given in full text. Upon request, the Contracting Officer will make their full text available. Also, the full text of a clause may be accessed electronically at this/these address(es):

http://farsite.hill.af.mi]/ http://www.acq.osd.mil/dpap/dars/dfars/

- (d) Inspection/Acceptance. See Section 1 of Purchase Order.
- (e) Excusable delays. The Contractor shall be fiable for default unless nonperformance is caused by an occurrence beyond the reasonable control of the Contractor and without its fault or negligence, such as acts of God or the public enemy, acts of the Government in either its sovereign or contractual capacity, fires, floods, epidemics, quarantine restrictions, strikes, unusually severe weather, and delays of common carriers. The Contractor shall notify the Contracting Officer in writing as soon as it is reasonably possible after the commencement of any excusable delay, setting forth the full particulars in connection therewith, shall remedy such occurrence with all reasonable dispatch, and shall promptly give written notice to the Contracting Officer of the cessation of such occurrence.
- (f) Termination for the Government's convenience. The Government reserves the right to terminate this contract, or any part hereof, for its sole convenience. In the event of such termination, the Contractor shall immediately stop all work hereunder and shall immediately cause any and all of its suppliers and subcontractors to cease work. Subject to the terms of this contract, the Contractor shall be paid a percentage of the contract price reflecting the percentage of the work performed prior to the notice of termination, plus reasonable charges that the Contractor can demonstrate to the satisfaction of the Government, using its standard record keeping system, have resulted from the termination. The Contractor shall not be required to comply with the cost accounting standards or contract cost principles for this purpose. This paragraph does not give the Government any right to audit the Contractor's records. The Contractor shall not be paid for any work performed or costs incurred that reasonably could have been avoided.
- (g) Termination for cause. The Government may terminate this contract, or any part hereof, for cause in the event of any default by the Contractor, or if the Contractor fails to comply with any contract terms and conditions, or fails to

provide the Government, upon request, with adequate assurances of future performance. In the event of termination for cause, the Government shall not be liable to the Contractor for any amount for supplies or services not accepted, and the Contractor shall be liable to the Government for any and all rights and remedies provided by law. If it is determined that the Government improperly terminated this contract for default, such termination shall be deemed a termination for convenience.

(End of Clause)

#### 6. ATTACHMENTS

Attachment I Statement of Work (7-18-11)

# DAPRA/TTO META Program Component Model Library

#### CMU-NREC Statement of Work

July 18, 2011

# **Overview**

This Statement of Work (SOW) outlines Carnegie Mellon University, National Robotics Engineering Center's (CMU-NREC) tasks planned for supporting DARPA TTO's META program. Under this effort NREC will prepare, package, and deliver unmanned ground vehicle (UGV) cooling system models to DARPA, and will provide technical support if requested in addressing questions related to and modifications to the models. The models will be utilized by the performers of the META program. This effort will fulfill the need for a set of system and component models sufficiently detailed to exercise the META tools currently under development. The META program is at a stage when tool maturation and integration requires the use of such a set of models. This purchase is essential to the completion of the META program.

# **Work Tasks**

#### Task 1: Select models

CMU-NREC will identify and extract the appropriate models from a complete set of models that currently exist for a field-proven experimental UGV (XV). Specific emphasis is placed on the various models and modeling functions that address the thermal management/cooling system of the XV.

CMU will extract and package the following:

- CAD models that capture the detailed geometry, dimensions, and mechanical interfaces. The original models are in SolidWorks format. XV's thermal management CAD model includes more than 700 part models.
- Thermal fluid-simulation models in KULI format. KULI is a one-dimensional
  thermal-fluid simulation software package with a block-diagram style GUI . For the
  XV program it was used to rapidly model candidate cooling topologies, simulate their
  performance and investigate the effects of system modifications while fine-tuning
  the design. XV's KULI model includes more than 600 part models.
- MATLAB-Simulink models and functions that were used to model XV heat rejection from various components and this data was fed into KULI for thermal-fluid (cooling system performance) simulation. The results from KULI were component and fluid temperatures, air and coolant flow rates and required cooling fan powers.
- Documents summarizing the XV thermal management system, cooling circuits, key components, and performance in Adobe pdf format.

# Task 2: Prepare models for use

This task represents a significant portion of the overall effort. It is expected that the following activities will be undertaken:

- Clean-up and reduce models as necessary: In response to specific needs and
  requirements of DARPA, CMU will further prepare specific portions of the XV
  thermal management model for the META Program performers. For example, focus
  may be placed on the cooling circuit of the XV engine pack, cooling of major
  electronics associated with the drivetrain, etc.
- CMU will simplify the design tree of the thermal management system and generate
  a discretization of subassemblies that will ease the abstraction of the XV models and
  potentially allow for multi-scale studies to be performed. CMU will generate a
  description of the design tree and definitions for the subassemblies.
- Check for model consistency and applicability: CMU will work to ensure that the
  selected models and code are prepared in a way that allows for use by parties with
  no specific knowledge of the XV design to the highest degree possible. CMU will run
  the thermal models to ensure that they are working properly. CMU will utilize its
  own SolidWorks and MATLAB/Simulink licenses to run and verify the models. CMU
  has also requested a zero-fee reapplication of its KULI license.
- Develop documentation that defines the models, model structure, interfaces between
  models, and process to run the models. CMU will prepare all required documentation
  to understand the content of the models and process to run them.

CMU will work with DARPA to prepare the models and relevant documentation in the best possible form to support the needs of the META Program.

#### Task 3: Deliver models to DARPA

CMU will deliver the models and associated documentation to DARPA as soon as that material receives Operations Security (OPSEC) clearance by the U.S. Army's Tank Automotive Research, Development and Engineering Center (TARDEC).

CMU engineers will work closely with DARPA personnel throughout this effort. As part of the delivery, CMU will provide training on the content of the models and process to run relevant simulations and sensitivity studies.

# Task 4: Provide post-delivery support

CMU will support DARPA in disseminating the models to the META program performers and will provide expertise to answer questions and clarify aspects of the design and simulation models as requested.

# **Deliverables**

Useable models of the thermal management system of CMU's XV, including:

- SolidWorks CAD mechanical part and assembly files
- KULI thermal modeling component and system model files
- MATLAB-Simulink files supporting KULI simulation
- Document describing XV's thermal management system, major cooling circuits, and summary performance
- Document describing model details, file content, simulation running instructions, input/output, etc.

# **Schedule**

Month 1: Tasks 1 and 2

Month 2: Tasks 2 and 3

Month 3: Task 4

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P00001	03-Jan-2012	7925/00		
6. ISSUED BY CODE	HR0011	7. ADMINISTERED BY (If other than item 6)	CODE	
DARPA CMO ATTN: CHRISTOPHER GLISTA 3701 N. FAIRFAX DR. ARLINGTON VA 22203	The end of the	See Item 6		
8. NAME AND ADDRESS OF CONTRACTOR	(No., Street, County, Str	ate and Zip Code)	9A. AMENDMENT OF	SOLICITATION NO.
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Offer must acknowledge receipt of this amendment (a) By completing Items 8 and 15, and returning or (c) By separate letter or telegram which includes a RECEIVED AT THE PLACE DESIGNATED FOR REJECTION OF YOUR OFFER. If by virtue of this provided each telegram or letter makes reference to to 12. ACCOUNTING AND APPROPRIATION DA	copies of the amendment reference to the solicitation THE RECEIPT OF OFFER amendment you desire to the solicitation and this amendment you desire to the solicitation and the solic	ent; (b) By acknowledging receipt of this amendment numbers. FAILURE OF YOUR AS PRIOR TO THE HOUR AND DATE SPECIFII change an offer already submitted, such change ma	nt on each copy of the offer su ACKNOWLEDGMENT TO I ED MAY RESULT IN y be made by telegram or lette	BE
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B. THE ABOVE NUMBERED CONTRACT/C office, appropriation date, etc.) SET FORTH				in paying
X C. THIS SUPPLEMENTAL AGREEMENT IS By mutual agreement of the Parties.	ENTERED INTO PURS	SUANT TO AUTHORITY OF:		
D. OTHER (Specify type of modification and a	uthority)			
E. IMPORTANT: Contractor is not,	X is required to sign	n this document and return 1 co	opies to the issuing office.	***
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Except as provided herein, all terms and conditions of the	document referenced in Iten	n 9A or 10A, as heretofore changed, remains unch	anged and in full force and effi	pet.
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15B. CONTRACTOR/OFFEROPERCE CONTRACTOR	VSC DATE SIGNED	16B. UNITED STATES OF AMERICA	A	16C. DATE SIGNED
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(Signature of person authorized to sign)	1/12/12	(Signature of Contracting Officer	)	

HR0011

#### SECTION SF 30 BLOCK 14 CONTINUATION PAGE

#### SUMMARY OF CHANGES

SECTION 18-23 - ADDITIONS TO DD FORM 1155

The following Delivery Schedule item for CLIN 0001 has been changed from:

DELIVERY DATE QUANTITY SHIP TO ADDRESS UIC

POP 02-SEP-2011 TO N/A DARPA HR0011

03-JAN-2012 PAUL EREMENKO

ATTN: TACTICAL TECHNOLOGY OFFICE

3701 NORTH FAIRFAX DRIVE ARLINGTON VA 22203-1714

571-218-4889 FOB: Destination

To:

DELIVERY DATE QUANTITY SHIP TO ADDRESS UIC

POP 02-SEP-2011 TO N/A DARPA

10-FEB-2012 PAUL EREMENKO

ATTN: TACTICAL TECHNOLOGY OFFICE

3701 NORTH FAIRFAX DRIVE ARLINGTON VA 22203-1714

571-218-4889 FOB: Destination

The following have been modified:

#### 2. PERFORMANCE

The term of the Purchase Order shall be from September 2, 2011 through February 10, 2012.

(End of Summary of Changes)

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P00002		14-Feb-12	7925/00				
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DARPA CMO			See Item 6				
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#### SECTION SF 30 BLOCK 14 CONTINUATION PAGE

SECTION 18-23 - ADDITIONS TO DD FORM 1155

#### SUMMARY OF CHANGES

SECTION 18-23 - ADDITIONS TO DD FORM 1155

The following Delivery Schedule item for CLIN 0001 has been changed from:

**DELIVERY DATE** 

QUANTITY

N/A

SHIP TO ADDRESS

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POP 02-SEP-2011 TO

10-FEB-2012

DARPA

HR0011

PAUL EREMENKO

ATTN: TACTICAL TECHNOLOGY OFFICE

3701 NORTH FAIRFAX DRIVE ARLINGTON VA 22203-1714

571-218-4889 FOB: Destination

To:

DELIVERY DATE

QUANTITY

N/A

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POP 02-SEP-2011 TO

12-MAR-2012

DARPA

HR0011

PAUL EREMENKO

ATTN: TACTICAL TECHNOLOGY OFFICE

3701 NORTH FAIRFAX DRIVE ARLINGTON VA 22203-1714

571-218-4889 FOB: Destination

The following have been modified:

#### 2. PERFORMANCE

The term of the Purchase Order shall be from September 2, 2011 through March 12, 2012.

(End of Summary of Changes)

P00003 19  ISSUED BY CODE HR00  DARPA CMO ATTN: CHRISTOPHER GLISTA 3701 N. FAIRFAX DR. ARLINGTON VA 22203	4. REQUISITION/PURCHASER SEE SCHEDULE  7. ADMINISTERED BY (If other	
DARPA CMO ATTN: CHRISTOPHER GLISTA 3701 N. FAIRFAX DR. ARLINGTON VA 22203		or than item 6) CODE
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	; 	n 6
NAME AND ADDRESS OF CONTRACTOR (No., Street, CARNEGIE MELLON UNIVERSITY 5000 FORBES AVE PITTSBURGH PA 15213-3815	County, State and Zip Code)	9A. AMENDMENT OF SOLICITATION NO.  9B. DATED (SEE ITEM 11)  X 10A. MOD. OF CONTRACT/ORDER NO. HR0011-11-P-0016
		10B. DATED (SEE ITEM 13)
	ACILITY CODE	X 02-Sep-2011
The above numbered solicitation is amended as set forth in Iter	IS ITEM ONLY APPLIES TO AMENDMENTS OF	FSOLICITATIONS
or (c) By separate letter or telegram which includes a reference RECEIVED AT THE PLACE DESIGNATED FOR THE RE REJECTION OF YOUR OFFER. If by virtue of this amenda provided each telegram or letter makes reference to the solicita	es of the amendment; (b) By acknowledging receipt of a to the solicitation and amendment numbers. FAILUR CETPT OF OFFERS PRIOR TO THE HOUR AND E ment you desire to change an offer already submitted, so tion and this amendment, and is received prior to the o	this amendment on each copy of the offer submitted; E OF YOUR ACKNOWLEDGMENT TO BE DATE SPECIFIED MAY RESULT IN such change may be made by telegram or letter.
2. ACCOUNTING AND APPROPRIATION DATA (If require See Schedule	ed)	
13. THIS ITEM A	PPLIES ONLY TO MODIFICATIONS OF CONTR S THE CONTRACT/ORDER NO. AS DESCRIBED	
A, THIS CHANGE ORDER IS ISSUED PURSUANT TO: (S CONTRACT ORDER NO. IN ITEM 10A.	Specify authority) THE CHANGES SET FORTH IN	NITEM 14 ARE MADE IN THE
B. THE ABOVE NUMBERED CONTRACT/ORDER IS MO office, appropriation date, etc.) SET FORTH IN ITEM 1 C. THIS SUPPLEMENTAL ACREEMENT IS ENTERED IN By Mutual Agreement of the Parties	4, PURSUANT TO THE AUTHORITY OF FAR 43	HANCES (such as changes in paying 3.103(B).
D. OTHER (Specify type of modification and authority)		
IMPORTANT: Contractor is not, X is	required to sign this document and return	1 copies to the issuing office.
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(b)(6)	Chris L. Glista (571) 218-4405	F CONTRACTING OFFICER (Type or print)  Christopher. Glista@darpa.mil
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APPROVED BY ORM 1-84

Prescribed by CSA FAR (48 CFR) 53.243

#### SECTION SF 30 BLOCK 14 CONTINUATION PAGE

#### The following items are applicable to this modification:

SECTION 18-23 - ADDITIONS TO DD FORM 1155

#### SUMMARY OF CHANGES

SECTION 18-23 - ADDITIONS TO DD FORM 1155

The total cost of this contract was increased by \$20,529.00 from \$94,999.00 to \$115,528.00.

**CLIN 0001** 

The CLIN extended description has changed

From:

'The Contractor shall support DARPA/TTO's META program in accordance with the Statement of Work - Attachment 1, dated July 18, 2011.'

To:

'The Contractor shall support DARPA/TTO's META program in accordance with the Statement of Work - Attachment 1.'

The unit price amount has decreased by \$49,827.00 from \$94,999.00 to \$45,172.00. The total cost of this line item has decreased by \$49,827.00 from \$94,999.00 to \$45,172.00.

CLIN 0002 is added as follows:

ITEM NO. 0002	SUPPLIES/SERVICES	QUANTITY 1	UNIT Lot	UNIT PRICE \$33,000.00	AMOUNT \$33,000.00
0002	META Component Mode	el Library	Lot	\$33,000.00	\$55,000.00
	FFP				
	In accordance with the St	atement of Work	- Attachment 1	, the Contractor shall	
	deliver the following:				
	- Monthly summary prog	ress update coveri	ng project activ	rity and CAD/structural	
	models. 03/31/2012				
	<ul> <li>Monthly summary prog</li> </ul>			vity and	
	Analytical/simulation mo	dels. 04/30/20	12		
	FOB: Destination				

NET AMT \$33,000.00

SUBCLIN 000201 is added as follows:

ITEM NO. 000201	SUPPLIES/SERVICES	QUANTITY	UNIT	UNIT PRICE	AMOUNT \$0.00
000201	Funding for CLIN 0002				φ0.00
	FFP AO 7925/00				
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	AO No. 7925/00				
				NET AMT	\$0.00
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CLIN 0003 is	added as follows:				
ITEM NO.	SUPPLIES/SERVICES	QUANTITY	UNIT	UNIT PRICE	AMOUNT
0003	META Component Mode	l el Library	Lot	\$37,356.00	\$37,356.00
	FFP In accordance with the St	atement of Work -	Attachment 1, the	Contractor shall	
	deliver the following: - Monthly summary prog	race undeta accorda	a municat antivity	the Colid Works	
	CAD mechanical part and	d assembly, and Stri	uctural, thermal, a		
	modeling component and - Files supporting simulat				
	- Final report including d	escription of XV's s	pecified subsyste		
	file content, simulation ru overall project performan FOB: Destination		input/output, etc.	, and summary of	
				NET AMT	\$37,356.00
SUBCLIN 000	0301 is added as follows:				
ITEM NO.	SUPPLIES/SERVICES	QUANTITY	UNIT	UNIT PRICE	AMOUNT
000301	Funding for CLIN 0003				\$0.00
	FFP AO 7925/00				
	FOB: Destination				
	AO No. 7925/00				
				NET AMT	\$0.00
	ACRN AA				\$16,827.00
	CIN: 000000000000000000000000000000000000	000000000000000000000000000000000000000			

SUBCLIN 000302 is added as follows:

ITEM NO. SUPPLIES/SERVICES QUANTITY UNIT UNIT PRICE AMOUNT 000302 \$0.00

Funding for CLIN 0003

**FFP** 

AO 7925/01 FOB: Destination AO No. 7925/01

NET AMT \$0.00

HR0011

HR0011

ACRN AB \$20,529.00

The following Delivery Schedule item for CLIN 0001 has been changed from:

DELIVERY DATE QUANTITY SHIP TO ADDRESS UIC

POP 02-SEP-2011 TO N/A DARPA

12-MAR-2012 PAUL EREMENKO

ATTN: TACTICAL TECHNOLOGY OFFICE

3701 NORTH FAIRFAX DRIVE ARLINGTON VA 22203-1714

571-218-4889 FOB: Destination

To:

DELIVERY DATE QUANTITY SHIP TO ADDRESS UIC

POP 02-SEP-2011 TO

12-MAR-2012

DARPA HR0011

LTC NATHAN WIEDENMAN, PHD TACTICAL TECHNOLOGY OFFICE 3701 NORTH FAIRFAX DRIVE ARLINGTON VA 22203-1714

703-248-1532 FOB: Destination

The following Delivery Schedule item has been added to CLIN 0002:

N/A

DELIVERY DATE QUANTITY SHIP TO ADDRESS UIC

POP 19-MAR-2012 TO N/A

30-APR-2012

DARPA

LTC NATHAN WIEDENMAN, PHD TACTICAL TECHNOLOGY OFFICE 3701 NORTH FAIRFAX DRIVE

ARLINGTON VA 22203-1714 703-248-1532

FOB: Destination

The following Delivery Schedule item has been added to CLIN 0003:

DELIVERY DATE QUANTITY SHIP TO ADDRESS UIC

POP 19-MAR-2012 TO N/A DARPA HR0011

15-JUN-2012 LTC NATHAN WIEDENMAN, PHD
TACTICAL TECHNOLOGY OFFICE
3701 NORTH FAIRFAX DRIVE
ARLINGTON VA 22203-1714

703-248-1532 FOB: Destination

Accounting and Appropriation

Summary for the Payment Office

As a result of this modification, the total funded amount for this document was increased by \$20,529.00 from \$94,999.00 to \$115,528.00.

SUBCLIN 000101:

SUBCLIN 000201:

Funding on SUBCLIN 000201 is initiated as follows:

ACRN: AA

Acctng Data: 9710400 1320 7925 P1M30 2525 DPAC 1 5362 S12136 62303E

Increase: \$33,000.00 Total: \$33,000.00

SUBCLIN 000301:

Funding on SUBCLIN 000301 is initiated as follows:

ACRN: AA

Acctng Data: 9710400 1320 7925 P1M30 2525 DPAC 1 5362 S12136 62303E

Increase: \$16,827.00 Total: \$16,827.00

SUBCLIN 000302:

Funding on SUBCLIN 000302 is initiated as follows:

ACRN: AB

Acctng Data: 9720400 1320 7925 P2M30 2525 DPAC 2 5202 S12136 62303E

Increase: \$20,529.00 Total: \$20,529.00

The following have been modified:

# 2. PERFORMANCE

The term of the Purchase Order shall be from September 2, 2011 through June 15, 2012.

# 3. PURCHASE ORDER ADMINISTRATIVE DATA

(c) For each invoice/cost voucher submitted for payment, the contractor shall also e-mail the WAWF automated invoice notice directly to the following points of contact:

Name	E-mail	Phone	Role
Chris Glista	christopher.glista@darpa.mil	(571) 218-4405	Contracting Officer
Nathan Wiedenman	nathan.wiedenman@darpa.mil	(703) 248-1532	META Program Manager

# 6. ATTACHMENTS

Attachment 1 - Statement of Work (3-12-12)

(End of Summary of Changes)

DAPRA/TTO META Program Component Model Library CMU-NREC Statement of Work Revised March 12, 2012

#### Overview

This Statement of Work (SOW) outlines Carnegie Mellon University, National Robotics Engineering Center's (CMU-NREC) tasks planned for supporting DARPA TTO's META program. Under this effort NREC will prepare, package, and deliver unmanned ground vehicle (UGV) cooling system models to DARPA, and will provide technical support if requested in addressing questions related to and modifications to the models. The models will be utilized by the performers of the META program. This effort will fulfill the need for a set of system and component models sufficiently detailed to exercise the META tools currently under development. The META program is at a stage when tool maturation and integration requires the use of such a set of models. This purchase is essential to the completion of the META program.

#### **Work Tasks**

#### Task 1: Select models

CMU-NREC will identify and extract the appropriate models from a complete set of models that currently exist for a field-proven experimental UGV (XV). Specific emphasis is placed on the various models and modeling functions that address the thermal management/cooling system of the XV.

CMU will extract and package the following:

- CAD models that capture the detailed geometry, dimensions, and mechanical
  interfaces. The original models are in SolidWorks format. XV's thermal management
  CAD model includes more than 700 part models.
- Thermal fluid-simulation models in KULI format. KULI is a one-dimensional thermal-fluid simulation software package with a block-diagram style GUI . For the XV program it was used to rapidly model candidate cooling topologies, simulate their performance and investigate the effects of system modifications while fine-tuning the design. XV's KULI model includes more than 600 part models.
- MATLAB-Simulink models and functions that were used to model XV heat rejection from various components and this data was fed into KULI for thermal-fluid (cooling system performance) simulation. The results from KULI were component and fluid temperatures, air and coolant flow rates and required cooling fan powers.
- Documents summarizing the XV thermal management system, cooling circuits, key components, and performance in Adobe pdf format.

# Task 2: Prepare models for use

This task represents a significant portion of the overall effort. It is expected that the following activities will be undertaken:

- Clean-up and reduce models as necessary: In response to specific needs and
  requirements of DARPA, CMU will further prepare specific portions of the XV
  thermal management model for the META Program performers. For example, focus
  may be placed on the cooling circuit of the XV engine pack, cooling of major
  electronics associated with the drivetrain, etc.
- CMU will simplify the design tree of the thermal management system and generate
  a discretization of subassemblies that will ease the abstraction of the XV models and
  potentially allow for multi-scale studies to be performed. CMU will generate a
  description of the design tree and definitions for the subassemblies.
- Check for model consistency and applicability: CMU will work to ensure that the selected models and code are prepared in a way that allows for use by parties with no specific knowledge of the XV design to the highest degree possible. CMU will run the thermal models to ensure that they are working properly. CMU will utilize its own SolidWorks and MATLAB/Simulink licenses to run and verify the models. CMU has also requested a zero-fee reapplication of its KULI license.
- Develop documentation that defines the models, model structure, interfaces between models, and process to run the models. CMU will prepare all required documentation to understand the content of the models and process to run them.

CMU will work with DARPA to prepare the models and relevant documentation in the best possible form to support the needs of the META Program.

#### Task 3: Deliver models to DARPA

CMU will deliver the models and associated documentation to DARPA as soon as that material receives Operations Security (OPSEC) clearance by the U.S. Army's Tank Automotive Research, Development and Engineering Center (TARDEC).

CMU engineers will work closely with DARPA personnel throughout this effort. As part of the delivery, CMU will provide training on the content of the models and process to run relevant simulations and sensitivity studies.

# Task 4: Provide post-delivery support

CMU will support DARPA in disseminating the models to the META program performers and will provide expertise to answer questions and clarify aspects of the design and simulation models as requested.

# Task 5: Models of chassis and structural subsystems

CMU-NREC will identify and extract the appropriate models from a complete set of models that currently exist for a field-proven experimental Unmanned Ground Vehicle (XV). Specific emphasis is placed on the various models and modeling functions that address the chassis and structural subsystems of the XV.

CMU will extract and package the following:

- CAD models that capture the detailed geometry, dimensions, and mechanical interfaces. The original models are in SolidWorks format.
- Structural, thermal, and/or fluid simulation models for the chassis and structural subsystems.
- MATLAB-Simulink models and functions that were used to support domain-specific models
- Documents summarizing the XV mobility system, key components, and performance in Adobe pdf format.
- Clean-up and reduce models as necessary.
- CMU will simplify the design tree of the chassis and structural subsystems and
  generate a discretization of subassemblies that will ease the abstraction of the XV
  models and potentially allow for multi-scale studies to be performed. CMU will
  generate a description of the design tree and definitions for the subassemblies.
- Check for model consistency and applicability: CMU will work to ensure that the
  selected models and code are prepared in a way that allows for use by parties with no
  specific knowledge of the XV design to the highest degree possible. CMU will run the
  models to ensure that they are working properly. CMU will utilize its own SolidWorks
  and MATLAB/Simulink licenses to run and verify the models.
- Develop documentation that defines the models, model structure, interfaces between models, and process to run the models. CMU will prepare all required documentation to understand the content of the models and process to run them.

CMU engineers will work closely with DARPA personnel throughout this effort. As part of the delivery, CMU will provide instructions on the content of the models and process to run relevant simulations and sensitivity studies.

#### Task 6: Consult to DARPA C2M2L efforts

For both C2M2L-1 and C2M2L-2 TAs 1&2, CMU will assist in a consulting role. Specific needs will be with respect to component and context models: what should these consist of and in what format(s)? CMU will provide a knowledgeable point of contact who is responsive to queries from ongoing modeling efforts in the Adaptive Vehicle Make portfolio. This individual should plan to attend the DARPA AVM PI meeting at Purdue University, March 20-22 2012, potentially hosting a workshop on these topics.

#### **Deliverables**

Useable models of the thermal management system of CMU's XV, including:

- SolidWorks CAD mechanical part and assembly files
- · KULI thermal modeling component and system model files
- MATLAB-Simulink files supporting KULI simulation
- Document describing XV's thermal management system, major cooling circuits, and summary performance
- Document describing model details, file content, simulation running instructions, input/output, etc.

#### Task 5 & 6 Milestones and Deliverables:

- CAD/structural models extracted 02/29/2012
- Analytical/simulation models extracted 03/15/2012
- CAD/structural models cleaned up reduced 03/31/2012
- Analytical/simulation models cleaned up and reduced 04/15/2012
- All models reduced and re-packaged 05/15/2012
- SolidWorks CAD mechanical part and assembly files 05/31/2012
- Structural, thermal, and/or fluid modeling component and system model files 05/31/2012
- MATLAB-Simulink files supporting simulations 05/31/2012
- Document describing XV's specified subsystems, and summary performance 06/15/2012
- Document describing model details, file content, simulation running instructions, input/output, etc. – 06/15/2012

AMENDMENT OF SOLICITATION	1. CONTRACT	T ID CODE	PAGE OF PAGES		
AMENDMENT OF SOLICITATION	MODIFICATIO	N OF CONTRACT	J		1 3
2. AMENDMENT/MODIFICATION NO. P00004	3. EFFECTIVE DATE 10-Aug-2012	4. REQUISITION/PURCHASE REQ. NO. SEE SCHEDULE	1 - 1 - 2 - 2 - 2 - 2 - 2 - 2 - 2	5. PROJECT	NO.(If applicable)
6. ISSUED BY CODE  DARPA CMO ATTN: CHRISTOPHER GLISTA 675 N. RANDOLPH STREET ARLINGTON VA 22203-2114	HR0011	7. ADMINISTERED BY (If other than item 6) DARPA CMO ATTN: CHRISTOPHER GLISTA 3701 N. FAIRFAX DR. ARLINGTON VA 22203	со	DE HR00	11
8. NAME AND ADDRESS OF CONTRACTOR CARNEGIE MELLON UNIVERSITY	(No., Street, County, St	tate and Zip Code)	9A. AMENDM	ENT OF SOL	LICITATION NO.
5000 FORBES AVE PITTSBURGH PA 15213-3815			9B. DATED (SI	EE ITEM 11)	
		)	10A. MOD. OF HR0011-11-P-	CONTRACT	ORDER NO.
CODE 97668	FACILITY COL	DE >	10B. DATED ( 02-Sep-2011	SEE ITEM 1	3)
	11. THIS ITEM ONLY	APPLIES TO AMENDMENTS OF SOLIC	ITATIONS		900
(a) By completing Items 8 and 15, and returning or (c) By separate letter or telegram which includes a RECEIVED AT THE PLACE DESIGNATED FOR REJECTION OF YOUR OFFER. If by virtue of this provided each telegram or letter makes reference to the second of t	reference to the solicitation THE RECEIPT OF OFFER amendment you desire to the solicitation and this amendment	RS PRIOR TO THE HOUR AND DATE SPECIFI change an offer already submitted, such change materials and submitted and such change materials.	ACKNOWLEDGME ED MAY RESULT IN ay be made by telegran	NT TO BE	d;
12. ACCOUNTING AND APPROPRIATION DA	TA (If required)				
		TO MODIFICATIONS OF CONTRACTS/ACT/ORDER NO. AS DESCRIBED IN ITE		8	2000
A. THIS CHANGE ORDER IS ISSUED PURS CONTRACT ORDER NO. IN ITEM 10A.	UANT TO: (Specify at	athority) THE CHANGES SET FORTH IN	ITEM 14 ARE MA	DE IN THE	
B. THE ABOVE NUMBERED CONTRACT/O office, appropriation date, etc.) SET FORTH				changes in pa	aying
C. THIS SUPPLEMENTAL AGREEMENT IS By Mutual Agreement of the Parties.	ENTERED INTO PUR	SUANT TO AUTHORITY OF:			
D. OTHER (Specify type of modification and au	uthority)	-			
E. IMPORTANT: Contractor is not,	X is required to sig	n this document and return 1 c	opies to the issuing	office.	
14. DESCRIPTION OF AMENDMENT/MODIFIC where feasible.)  Modification Control Number: cglista121:  The purpose of this modification is to extend the details.	109		Ť		ient. See page 2 f
Except as provided herein, all terms and conditions of the of the NAME AND TITLE OF SIGNER (Types of the conditions)		m 9A or 10A, as heretofore changed, remains unch			rint)
(1)(6)	200000	CHRISTOPHER L. GLISTA TEL: (571) 218-4405	EMAIL: christoph		t 15
(6)		16B. UNITED STATES OF AMERIC		1	DATE SIGNED
	8/9/12	BY (Signature of Contracting Office	r)		
	3	0-105-04	STA Prese	NDARD FOR	

#### SECTION SF 30 BLOCK 14 CONTINUATION PAGE

#### SUMMARY OF CHANGES

SECTION 18-23 - ADDITIONS TO DD FORM 1155

#### CLIN 0003

The CLIN 0003 extended description has changed from:

In accordance with the Statement of Work - Attachment 1, the Contractor shall deliver the following:

- Monthly summary progress update covering project activity, the Solid Works CAD mechanical part and assembly, and Structural, thermal, and/or fluid modeling component and system model files. 05/31/2012
- Files supporting simulations. 05/31/2012
- Final report including description of XV's specified subsystems, model details, file content, simulation running instructions, input/output, etc., and summary of overall project performance. 6-Jun-12

#### TO:

In accordance with the Statement of Work - Attachment 1, the Contractor shall deliver the following:

- Monthly summary progress update covering project activity, the Solid Works CAD mechanical part and assembly, and Structural, thermal, and/or fluid modeling component and system model files. 05/31/2012
- Files supporting simulations. 05/31/2012
- Final report including description of XV's specified subsystems, model details, file content, simulation running instructions, input/output, etc., and summary of overall project performance. No later than 30-Nov-12.

The following Delivery Schedule item for CLIN 0003 has been changed from:

DELIVERY DATE	QUANTITY	SHIP TO ADDRESS	UIC
POP 19-MAR-2012 TO 15-JUN-2012	N/A	DARPA LTC NATHAN WIEDENMAN, PHD TACTICAL TECHNOLOGY OFFICE 3701 NORTH FAIRFAX DRIVE ARLINGTON VA 22203-1714 703-248-1532 FOB: Destination	HR0011

To:

DELIVERY DATE	QUANTITY	SHIP TO ADDRESS	UIC
POP 19-MAR-2012 TO 30-NOV-2012	N/A	DARPA LTC NATHAN WIEDENMAN, PHD TACTICAL TECHNOLOGY OFFICE 3701 NORTH FAIRFAX DRIVE ARLINGTON VA 22203-1714 703-248-1532 FOB: Destination	HR0011

The following have been modified:

# 2. PERFORMANCE

The term of the Purchase Order shall be from September 2, 2011 through November 30, 2012.

(End of Summary of Changes)

All other terms and conditions of purchase order HR0011-11-P-0016 shall remain in full force and effect, unless otherwise stated in Modification P00004 herein.

Agreement No.: HR0011-16-2-0021 Purchase Request No.: HR0011621740

Effective Date: April 29, 2016 DARPA's CFDA Number: 12.910

DODDAC: HR0011

Issued by:

Defense Advanced Research Projects Agency (DARPA)

Contracts Management Office (CMO)

675 North Randolph Street Arlington, VA 22203-2114

(Attn: Michael S. Mutty, 571-218-4588, michael.mutty@darpa.mil)

Recipient:

Carnegie Mellon University

5000 Forbes Avenue

Pittsburgh, PA, 15213-3815

(Attn:(b)(6)

Recipient Identification Numbers/Codes:

DUNS (b)(4)
CAGE
TIN:

Total Cooperative Agreement Amount: \$998,910.00

Accounting and Appropriation Data:

SUBCLIN

ACRN

0001/01

AA

**FUND CITE** 

012199 097 0400 000 N 20162017 D 1320 DRVLDD

2016.MS-01.CORE.A

DARPA 255

**AMOUNT** 

\$514,203.00

Payment Office Information:

DFAS IN VP DAI DARPA

8899 East 56th Street

Indianapolis, IN 46249-1500

DODAAC: HQ0685

[AWARD SUBJECT TO ELECTRONIC FUNDS TRANSFER (EFT) REQUIREMENT]

Authority: This Agreement is issued pursuant to the authority of 10 U.S.C. § 2358, as amended.

#### COOPERATIVE AGREEMENT SCHEDULE

- 1. Purpose: The purpose of this Cooperative Agreement is to fund research to the Recipient to carry out a public purpose of support or stimulation of the Defense Advanced Research Projects Agency (DARPA) Defense Sciences Office (DSO) Revolutionary Enhancement of Visibility by Exploiting Active Lightfields (REVEAL) Program. This effort shall be carried out generally as set forth in Exhibit B. Research Description Document, dated March 28, 2016.
- 2. Term: The term of this Cooperative Agreement commences on April 29, 2016 and continues through April 28, 2018.
- (a) The Recipient shall make all requests for no-cost period of performance extensions, in writing, to the Administrative Agreements Officer, no later than 30 days prior to the end of the current period of performance. The Administrative Agreements Officer is delegated authority to grant such request, via modification to the Cooperative Agreement, after receiving approval from the Agreement Officer's Representative.
- 3. Terms and Conditions: This Cooperative Agreement is subject to the terms and conditions set forth in the attached Exhibit A, entitled "DARPA AGENCY SPECIFIC TERMS AND CONDITIONS," dated January 2016 and to any special terms and conditions in this Cooperative Agreement Schedule.
- 4. Agreement Officer's Representative: The Agreement Officer's Representative (AOR) representing the Government under this Cooperative Agreement is:

Dr. Ravindra Athale Office of Naval Research 875 North Randolph Street Arlington, VA 22203 Phone#: 703-588-1916

E-mail: ravindra.athale@navy.mil

DoDAAC No.: N00014

5. DARPA Program Manager: The DARPA Program Manager (PM) representing the Government under this Cooperative Agreement is:

> Defense Advanced Research Projects Agency Defense Sciences Office (DSO) ATTN.: Dr. Predrag Milojkovic 675 North Randolph Street Arlington, VA 22203-2114 Phone#: 703-526-2845

E-mail: predrag.milojkovic@darpa.mil

DoDAAC No.: HR0011

6. <u>Administrative Agreements Office</u>: The Administrative Agreement Office (AAO) for this Cooperative Agreement is:

Office of Naval Research (ONRRO) Chicago Chicago Regional Office 230 South Dearborn, Room 380 Chicago, IL 60605-1595 Phone#: 312-886-5423

E-mail: onr chicago@navy.mil

DoDAAC#: N62880

7. Principal Investigator: The Principal Investigator shall be responsible for this effort.

Carnegie Mellon University
Attn: (b)(4); (b)(6)
5000 Forbes Avenue
Pittsburgh, PA, 15213-3815
Phone#: (b)(4); (b)(6)
E-mail:

The Recipient agrees to notify the AAO before changing the Principal Investigator.

8. Cooperative Agreement Funding: This Cooperative Agreement is incrementally funded in the amount of \$514,203.00. The Government's obligation to make payments to the Recipient is limited to only those funds obligated by this Cooperative Agreement or by modification to this Cooperative Agreement. Subject to availability of funds and continued satisfactory progress on the Cooperative Agreement as determined by the Government, the Government agrees to provide funding according to the following schedule:

FY16: \$484,707.00

The Cooperative Agreement Awardee shall notify the AAO in writing promptly whenever the total Cooperative Agreement amount is expected to exceed the needs of the Cooperative Agreement Awardee for the project period by more than 5% of the award. This notification shall not be required if an application for additional funding is submitted for a continuation award.

- 9. <u>Payments</u>: Payments will be made to the Recipient on a reimbursement basis and shall be made by electronic funds transfer in accordance with the account information provided to the System for Award Management.
- 10. <u>Substantial Involvement</u>: Substantial involvement is expected between the U. S. Government and the Recipient when carrying out the activity contemplated in this Cooperative Agreement. It will include the U. S. Government's (a) sharing responsibility for the management, control, direction, or performance of the project, and (b) retaining the right to intervene in the conduct or performance of the project. The substantial involvement will include the U.S. Government's direction of activities to develop the research protocols necessary to complete the work and the approval of analysis mechanisms. The U.S.

Government, DARPA, will participate in the presentation of research results, the analysis of data, and the selection of analysis methods.

#### 11. List of Exhibits:

Exhibit A - DARPA Cooperative Agreement General Terms and Conditions (January 2016) Exhibit B - Research Description Document (March 28, 2016)

FOR CARNEGIE MELLON UNIVERSITY FOR THE UNITED STATES OF AMERICA, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (b)(4); (b)(6) MUTTY.MICHAE Digitally signed by MUTTY.MICHAEL (b)(6) Date: 2016.04.29 07:27:30 -04'00' MICHAEL S. MUTTY (Signature) Agreements Officer Contracts Management Office (b)(4); (b)(6) 4/29/2016 (Name, Title) (Date) 1-28-16 (Date)

# EXHIBIT A JANUARY, 2016 DARPA AGENCY SPECIFIC TERMS AND CONDITIONS

This award is subject to the DoD Research and Development (R&D) general terms and conditions, which can be found at <a href="http://www.onr.navy.mil/Contracts-Grants/submit-proposal/grants-proposal/grants-terms-conditions.aspx">http://www.onr.navy.mil/Contracts-Grants/submit-proposal/grants-proposal/grants-terms-conditions.aspx</a> under the header "DoD Research and Development General Terms and Conditions," dated October 2015, and are incorporated herein. The DARPA Agency Specific Terms and Conditions supplement the DoD Research and Development general terms and conditions. This document addresses agency-specific concerns in addition to the above referenced regulations. Award recipients (hereafter, recipient) are accountable for all applicable statutory and regulatory requirements that govern these awards, even if not specifically listed in this document or documents referenced herein.

#### ORDER OF PRECEDENCE

Any inconsistencies in the requirements of this award shall be resolved in the following order:

- Federal statutes
- Federal regulations
- 2 CFR part 200, as modified and supplemented by DoD's interim implementation found in 2 CFR part 1103
- Award-specific terms and conditions (DARPA Agency Specific terms and conditions)
- DoD Research and Development general terms and conditions

In case of disagreement with any requirements of this award, the recipient shall contact the Agreements Officer listed in the award document in order to resolve the issue. The recipient shall not assess any costs to the award or accept any payments until the issue is resolved.

- 1. Research Responsibility
- 2. Amendment of Award
- 3. Payments
- 4. Prior Approvals
- 5. Reports and Reports Distribution
- 6. Public Release or Dissemination of Information
- 7. Acknowledgment of Sponsorship
- 8. Intellectual Property Matters
- 9. Activities Abroad
- 10. Security
- 11. Research Involving Recombinant DNA Molecules
- 12. Restrictions on Printing
- 13. Prohibition on Awarding to Entities that Require Certain Internal Confidentiality Agreements

#### 1) Research Responsibility:

- a) The recipient has full responsibility for the conduct of the research activity supported by this award, in accordance with the recipient's proposal, and the terms and conditions specified in this award. Recipients are encouraged to suggest or propose to discontinue or modify unpromising lines of investigation or to explore interesting leads which may appear during the development of the research. However, they must consult the Agreement Officer's Representative (AOR) through the Administrative Agreements Officer (AAO) before significantly deviating from the objectives or overall program of the research originally proposed.
- b) The recipient shall immediately notify the Agreements Officer of developments that have a significant impact on the award-supported activities. Also, notification shall be given in the case of problems, delays, or adverse conditions which materially impair the ability to meet the objectives of the award. This notification shall include a statement of the action taken or contemplated, and any assistance needed to resolve the situation.
  - 2) <u>Amendment of Award</u>: The only method by which this award can be amended is by a formal, written amendment signed by either the Agreements Officer or the AAO. No other communications, whether oral or in writing, shall modify this award.

# 3) Payments:

- a) Submitting Payments Through Wide Area Work Flow (WAWF): All payments shall be made by funds transfers to the bank account registered in the System for Award Management (SAM), <a href="http://www.sam.gov">http://www.sam.gov</a>. The recipient agrees to maintain its registration in SAM, including information necessary to facilitate payment via Electronic Funds Transfer (EFT). Should a change in registry or other incident necessitate the payment to an account other than that maintained in SAM, it is the recipient's responsibility to notify the AAO and obtain a modification to this award reflecting the change. The Government shall not be held responsible for any misdirection or loss of payment which occurs as the result of a recipient's failure to maintain correct/current EFT information within its SAM registration.
  - 1) Any request for advance payments must be approved by the AAO at the Administrative Office designated in the award document.
  - 2) Wide Area Work Flow (WAWF) has been designated as the Department of Defense standard for electronic invoicing and payment. Electronic submission of payment requests requires the recipient to register in WAWF and have the appropriate CAGE code activated. The recipient's SAM Electronic Business Point of Contact (EBPOC) is responsible for activating the CAGE code in WAWF by calling 1-866-618-5988. Once the recipient's CAGE Code is activated, the SAM EBPOC will self-register in WAWF (<a href="https://wawf.eb.mil">https://wawf.eb.mil</a>) and follow the instructions for a group administrator. The ONR Regional Offices will assist in this process. The ONR Regional Office is listed as the Administrative Office in the award document. Please call the ONR Regional Office with any questions regarding access to or use of WAWF.

# 4) Prior Approvals:

In addition to the prior approvals required by the DoD R&D general terms and conditions, prior written approval is required for the following actions:

- The subaward, transfer, or contracting out of any work under this award, unless described in the recipient's proposal and specifically approved and funded in the Award Schedule.
   The recipient's request for approval shall include the following supporting data:
  - (i) Basis for contractor selection;
  - (ii) Justification for lack of competition when competitive bids or offers are not obtained;
  - (iii) Basis for award cost or price, to include price or cost analysis performed by the recipient; and
  - (iv) Approval of the AOR.
- 5) Reports and Reports Distribution: Reports shall be furnished as specified below:
  - a) Report Types.
    - 1) Quarterly R&D Status Report This report, due 30 days after the reporting period, shall keep the Government informed of Recipient activity and progress toward accomplishment of Agreement objectives and advancement in state-of-the-art on the research and development including progress made toward achieving program performance goals. In addition, this report shall include the following business-related details: summarized details of the status of resources; accounting of expenditures for the period covered by the report in addition to cumulative expenditures to date; comparison of resource status with any payment and expenditure schedules or plans provided in the original proposal; explanation of any major deviations from those schedules; and discussion of proposed actions to address the deviations.
    - 2) Special Technical Report This report, due as required, shall document the results of a significant task, test, event or symposium.
    - 3) Final Technical Report This report, due 90 days after expiration or termination of the award, shall document the results of the complete effort. It shall contain brief information on each of the following:
    - a) A comparison of actual accomplishments with the goals and objectives established for the award, the findings of the investigator, or both.
      - b) Reasons why established goals were not met, if appropriate.
      - c) Other pertinent information.
    - 4) Final Financial Status Report This report, due 90 days after completion of the award, shall be submitted on a Standard Form 425 "Federal Financial Report (FFR)". The report shall be on a cash or accrual basis, depending on how the recipient's accounting records are normally kept.
    - 5) Report of Federal Cash Transactions [applicable only to advance payment awards] This report, due 15 days following the end of each quarter, shall be submitted on a Standard Form 425. The recipient shall provide forecasts of Federal cash requirements in the "Remarks" section of the report.

# b) Report Distribution:

Addresses	Report Types [7.(a)]	Number of Copies
Agreement Officer's Representative Email: <a href="mailto:ravindra.athale@navy.mil">ravindra.athale@navy.mil</a>	1, 2, 3, 4, 5	Ï
DARPA Program Manager Email: <u>predrag.milojkovic@darpa.mil</u>	1, 2, 3, 4, 5	1
Administrative Agreements Officer E-mail: onr_chicago@navy.mil	1, 3, 4, 5	1
DARPA Agreements Officer Email: ReportsDSO@darpa.mil	1, 3, 4, 5	1
DARPA/Research Support Center Email: <u>Researchsupport@darpa.mil</u>	3	1
Defense Technical Information Center ATTN: DTIC-O 8725 John J. Kingman Road Ft. Belvoir, VA 22060-6218	3	2
or		1
Email: TR@dtic.mil		1

#### 6) Public Release or Dissemination of Information

- a) At this time, DARPA expects the work performed under this award to be fundamental research, and it is, therefore, not subject to publication restrictions. Papers resulting from unclassified contracted fundamental research are exempt from prepublication controls and requirements, pursuant to DoD Instruction 5230.27 dated October 6, 1987.
- b) All papers resulting from this award will include the following distribution statement:
  - "Approved for public release; distribution is unlimited."
- c) Should the character of the research change during award performance so that the research is no longer considered fundamental, the award will be modified to impose the restrictions on public release and dissemination of information that apply to those research efforts that are not considered fundamental research.

# 7) Acknowledgment of Sponsorship:

a) The recipient agrees that in the release of information relating to this award, such release shall include a statement to the effect that (1) the project or effort depicted was or is sponsored by the Defense Advanced Research Projects Agency, (2) the content of the information does not necessarily

reflect the position or the policy of the Government, and (3) no official endorsement should be inferred.

- b) For the purpose of this article, information includes news releases, articles, manuscripts, brochures, advertisements, still and motion pictures, speeches, trade association proceedings, symposia, etc.
- d) Nothing in the foregoing shall affect compliance with the requirements of the clause entitled "Security."
- 8) <u>Intellectual Property Matters</u>: Questions regarding intellectual property matters should be referred to Agreements Officer.

All patent reports (interim and final) shall be submitted using the i-Edison.gov reporting website (<a href="http://s-edison.info.nih.gov/iEdison">http://s-edison.info.nih.gov/iEdison</a>). In the event the recipient is unable to submit reports through i-Edison, the recipient may utilize DD Form 882, Report of Inventions and Subcontracts, for submission of interim and final invention reports. The DD Form 882 and all invention disclosures shall be submitted to the AAO for proper disposition and forwarding to the Agreements Officer.

- 9) Activities Abroad: The recipient shall assure that project activities carried on outside the United States are coordinated as necessary with appropriate Government authorities and that appropriate licenses, permits, or approvals are obtained prior to undertaking proposed activities. The awarding agency does not assume responsibility for recipient compliance with the laws and regulations of the country in which the activities are to be conducted.
- 10) Security: The recipient may not be granted access to classified information under this award. If security restrictions should happen to apply to certain aspects of the proposed research, the recipient will be so informed. In the event that the scientific work under this award may need classification, or involve access to or storage of any classified data, the Government shall make its decision on the need to classify, or require such access or storage, within 30 days after receipt of written notice from the recipient. If the decision is affirmative, the Government shall invoke the clause in reference to the "Termination" proceedings in the DoD R&D general terms and conditions.
- 11) Research Involving Recombinant DNA Molecules: Any recipient performing research involving recombinant DNA molecules and/or organisms and viruses containing recombinant DNA molecules agrees, by acceptance of this award, to comply with the National Institutes of Health "Guidelines for Research Involving Recombinant DNA Molecules," July 5, 1994 (59 FR 34496) as amended, or such later revision of those guidelines as may be published in the Federal Register.

# 12) Restrictions on Printing:

Unless otherwise authorized in writing by the AAO, reports, data, or other written material produced using funds provided by this award and submitted hereunder shall be reproduced only by duplicating processes and shall not exceed 5,000 single page reports or a total of 25,000 pages of a multiple page report. These restrictions do not preclude the writing, editing, and preparation of manuscript or reproducible copy of related illustrative materials if required as a part of this award, or incidental printing such as forms or materials necessary to be used by the recipient to respond to the terms of the award. To satisfy the requirements of the Defense Technical Information Center, at least one copy of

each technical report submitted to the Defense Technical Information Center must be black typing or reproduction of black on white paper or suitable for reproduction by photographic techniques. Reprints of published technical articles are not within the scope of this paragraph.

In accordance with Executive Order 12873, dated October 20, 1993, as amended by Executive Order 12995, dated March 25, 1996, the recipient is encouraged to submit paper documents, such as letters or reports, that are printed/copied double-sided on recycled paper that has at least 30 percent postconsumer material.

# 13) Prohibition on Awarding to Entities that Require Certain Internal Confidentiality Agreements

- a) The recipient shall not require employees, contractors, or subrecipients seeking to report fraud, waste, or abuse to sign or comply with internal confidentiality agreements or statements prohibiting or otherwise restricting such employees or contractors from lawfully reporting such waste, fraud, or abuse to a designated investigative or law enforcement representative of a Federal department or agency authorized to receive such information.
- b) The recipient must notify its employees, contractors, or subrecipients that the prohibitions and restrictions of any internal confidentiality agreements inconsistent with paragraph (a) of this award provision are no longer in effect.
- c) The prohibition in paragraph (a) of this award provision does not contravene requirements applicable to any form issued by a Federal department or agency governing the nondisclosure of classified information.
- d) If the Government determines that the recipient is not in compliance with this award provision, it:
  - 1) Will prohibit the recipient's use of any FY 2016 or FY 2015 funds under this award, in accordance with Federal appropriations law; and
  - 2) May pursue other remedies available for the recipient's material failure to comply with award terms and conditions.

# RESEARCH DESCRIPTION DOCUMENT March 28, 2016

Summary: The objective of this effort is to seek to unlock the potential of indirect light transport events. This effort will focus on a general class of computational imaging systems that are "transport-aware" so that photons can be selectively prevented from contributing to an image based on the actual 3D light path followed.

Descriptions of tasks and deliverables are described below:

#### Year 1

# Task 1 - Thrust A: Theory and Systems for Light Transport Parsing

 Develop mathematical formulation and algorithms for parsing by solving an optimization function that separates the light paths while maximizing energy efficiency.

#### Subtasks:

- 1. Low-frequency, high-frequency and light field transport parsing
- 2. Explore Near Infra-Red imaging for transport parsing
- 3. Bounce decomposition
- 4. Fabrication of sensor for two-bucket transport parsing
- 5. Combine geometry and time-of-flight for parsing.

**Objective:** To develop the theory of light transport parsing by separating light paths into interesting sub-paths (both direct and indirect) that are useful for understanding both the LOS and non-LOS scenes.

**Deliverables:** Quarterly reports on performances of light transport parsing and annual prototype demonstrations for parsing.

# Task 2: Thrust B: Scene Reconstruction by Light Transport Parsing

- Develop bounce based decomposition to recover 3D structure and material properties of scenes
- Develop reduced model based optimization for Analysis by Synthesis with guarantees for convergence and sampling rates

**Objective:** Develop methods for reconstruction of both line of sight and non-line of sight scenes using the results obtained in the light transport parsing task (Thrust A).

#### Subtasks:

- 1. Reduce models for planar and non-planar transport, diffuse indirect LOS and NLOS scenes
- 2. 2-, 3-, 4-, bounce models for BRDF estimation
- 3. Investigate non-linear embeddings for model reduction
- 4. Reduce models for transient light transport

**Deliverables:** Quarterly reports on the performances reduced models for scene reconstruction including validation and accuracy estimation for datasets collected.

#### Year 2

#### Task 1 - Thrust A: Theory and Systems for Light Transport Parsing

 Develop mathematical formulation and algorithms for parsing by solving an optimization function that separates the light paths while maximizing energy efficiency

**Objective:** Continue developing the theory of light transport parsing by separating light paths into interesting sub-paths (both direct and indirect) that are useful for understanding both the line-of-sight and non-line-of-sight scenes

#### Subtasks:

- 1. Decompose transport paths into long range and near range, specular and diffuse indirect
- 2. Develop theory of light-field-based transport parsing
- 3. Investigate energy-efficient two-bucket parsing
- 4. Iterate on design and fabrication of sensor for two-bucket transport parsing
- 5. Study recoverability and limitations of each node in the transport parse tree

**Deliverables:** Quarterly reports on performances of light transport parsing and annual prototype demonstrations.

#### Task 2: Thrust B: Scene Reconstruction by Light Transport Parsing

- Develop bounce based decomposition to recover 3D structure and material properties of scenes
- Develop reduced model based optimization for Analysis by Synthesis with guarantees for convergence and sampling rates

**Objective:** Continue developing methods for reconstruction of both line of sight and nonline of sight scenes using the results obtained in the light transport parsing task (Thrust A).

#### Subtasks:

- 1. Simultaneous transport parsing and bounce graph based reconstruction
- 2. Simultaneous transport parsing and reduced model based reconstruction
- 3. Collect large dataset with different objects for LOS and NLOS scenes
- 4. Design adaptive imaging with fast reduced model based reconstruction
- 5. Demonstrate and evaluate LOS/NLOS reconstruction for complex geometries
- 6. Analyze recoverability of BRDF/BSSRDFs for opaque and translucent objects

**Deliverables:** Quarterly reports on the performances reduced models for scene reconstruction including validation and accuracy estimation for datasets collected

# Milestone Schedule for Year 1

Tasks	Milestones	Timeframe
Thrust A	<ul> <li>Low-frequency, high-frequency transport parsing</li> <li>Explore Near Infra-Red imaging for transport parsing</li> </ul>	3 months from award
Thrust B	<ul> <li>Reduced models for planar and non-planar transport components</li> <li>Reduced models for diffuse indirect LOS and NLOS</li> <li>2-Bounce models for BRDF estimation</li> </ul>	3 months from award
Thrust A	<ul> <li>Bounce decomposition (2-, 3-, 4- bounces)</li> <li>Fabricate PCB-based test platform for 1st-generation CMOS sensors</li> <li>Derive energy efficient metrics for low/high-frequency, bounce parsing</li> </ul>	6 months from award
Thrust B	<ul> <li>Reduced models for bounce decompositions</li> <li>Investigate non-linear embeddings instead of linear reduced models</li> <li>Shape estimation from 3-bounce and higher-order bounces</li> </ul>	6 months from award
Thrust A	<ul> <li>Two-bucket transport parsing with 1st-gen CMOS sensor</li> <li>Derive energy efficient coding for light field parsing</li> <li>Test time-of-flight and epipolar imaging on the same 1st-gen CMOS sensor</li> <li>Implement parsing using 1st-gen CMOS sensor</li> </ul>	9 months from award
Thrust B	<ul> <li>Reduced models for light field-based parsing</li> <li>Optimality guarantees for reduced model based inverse rendering</li> <li>Evaluate reconstruction accuracy and ambiguities of LOS and NLOS scenes</li> </ul>	9 months from award
Thrust A	<ul> <li>Develop general theory of two-bucket transport parsing</li> <li>Combine time-of-flight and epipolar constraints for better path selectivity</li> <li>Build prototype of energy efficient episcan ToF sensor for transport parsing</li> <li>Submit 2nd-gen sensor design to CMOS fabrication facility</li> </ul>	12 months from award
Thrust B	<ul> <li>Complete taxonomy of shape/reflectance estimation from multi-bounce graphs</li> <li>Build reduced models for transient transport components</li> <li>Demonstrate LOS/NLOS reconstruction for simple shapes using prototypes</li> </ul>	12 months from award

# Milestone Schedule for Year 2

Tasks	Milestones	Timeframe
Thrust A	<ul> <li>Decompose transport paths into long range and near range</li> <li>Investigate energy-efficient two-bucket parsing</li> <li>Develop theory of light-field-based transport parsing</li> <li>Test deeper transport parsing nodes with two-bucket 1st-gen CMOS sensor</li> </ul>	15 months from award
Thrust B	<ul> <li>Simultaneous transport parsing and bounce graph based reconstruction</li> <li>Simultaneous transport parsing and reduced model based reconstruction</li> </ul>	15 months from award
Thrust A	<ul> <li>Decompose paths into specular and diffuse indirect</li> <li>Decompose paths into translucent indirect, diffuse indirect, specular indirect</li> <li>Build light-field transport parsing prototype using 1st-gen sensor</li> <li>Initial testing of 2nd-gen CMOS sensor</li> </ul>	18 months from award
Thrust B	<ul> <li>Collect large dataset with different objects for LOS and NLOS</li> <li>Evaluate feasibility of different multi-modal transport prototypes for the dataset</li> <li>Investigate fundamental limitations of each transport node for reconstruction</li> </ul>	18 months from award
Thrust A	<ul> <li>Iterate on the two-bucket and ToF combination design for CMOS</li> <li>Integrate 2nd-gen sensor into our time-of-flight/light-field-based prototypes</li> <li>Finalize design of 3rd-gen programmable CMOS sensors</li> </ul>	21 months from award
Thrust B	<ul> <li>Design adaptive imaging with fast reduced model based reconstruction</li> <li>Analyze recoverability of BRDF/BSSRDFs for opaque and translucent objects</li> </ul>	21 months from award
Thrust A and B	<ul> <li>Demonstrate and evaluate LOS/NLOS reconstruction for complex geometries</li> <li>Study recoverability and limitations of each node in the transport parse tree</li> <li>Test energy efficiencies of the prototypes in the presence of ambient light</li> <li>Study accuracy tradeoffs with acquisition times</li> </ul>	24 months from award

# **Additional Deliverables:**

- Quarterly reports detailing the progress made in the previous quarter including: theoretical foundations, algorithms for estimation, experimental results, evaluation of limitations and the next steps
- 2. Datasets distributed in an open platform
- 3. Annual demonstrations of the prototype systems
- 4. Exchanging ideas at forums with researchers
- 5. Publish the results in highly competitive conferences and journals.

Agreement No.: HR0011-16-2-0021 Purchase Request No.: HR0011622709

Modification No.: P00001 Effective Date: May 16, 2016 DARPA's CFDA Number: 12.910

DODDAC: HR0011

Issued by:

Defense Advanced Research Projects Agency (DARPA)

Contracts Management Office (CMO)

675 North Randolph Street Arlington, VA 22203-2114

(Attn: Michael S. Mutty, 571-218-4588, michael.mutty@darpa.mil)

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5000 Forbes Avenue

Pittsburgh, PA, 15213-3815

(Attn:(b)(4);(b)(6)

# Recipient Identification Numbers/Codes:

DUNS: (b)(4) CAGE: TIN:

Total Cooperative Agreement Amount: \$998,910.00

Accounting and Appropriation Data:

SUBCLIN

ACRN

0001/01

AA

FUND CITE

012199 097 0400 000 N 20162017 D 1320 DRVLDD

2016.MS-01.CORE.A

DARPA 255

AMOUNT

\$484,707.00

Payment Office Information:

DFAS IN VP DAI DARPA

8899 East 56th Street

Indianapolis, IN 46249-1500

DODAAC: HQ0685

#### [AWARD SUBJECT TO ELECTRONIC FUNDS TRANSFER (EFT) REQUIREMENT]

Authority: This Agreement is issued pursuant to the authority of 10 U.S.C. § 2358, as amended.

#### COOPERATIVE AGREEMENT SCHEDULE

Add to the Purpose as follows:

1. <u>Purpose</u>: The purpose of this modification is to provide an increment of funds in the amount of \$484,707.00 to fully fund the Cooperative Agreement.

Revise Cooperative Agreement Funding as follows:

8. Cooperative Agreement Funding: This Cooperative Agreement is fully funded in the amount of \$998,910.00. The Government's obligation to make payments to the Recipient is limited to only those funds obligated by this Cooperative Agreement or by modification to this Cooperative Agreement. The Cooperative Agreement Awardee shall notify the AAO in writing promptly whenever the total Cooperative Agreement amount is expected to exceed the needs of the Cooperative Agreement Awardee for the project period by more than 5% of the award. This notification shall not be required if an application for additional funding is submitted for a continuation award.

FOR THE UNITED STATES OF AMERICA,
DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

0)(6)	
	5/16/2016
MICHAEL S. MUTTY	Date
Agreements Officer	200