

CRAFTING
THE FUTURE

Optimization of Radiator-Fan Distance Using 1D & 3D Simulation for Enhanced Thermal Performance

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15th May 2025



TTR Portfolio

TTR Methodology for Heat Exchanger Design

1D Simulation Methodology Using KULI

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TTR Portfolio



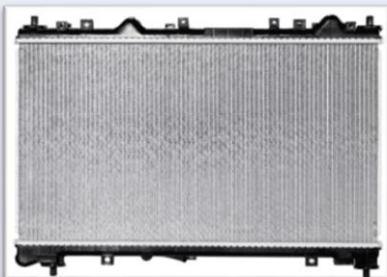
-
- Plant**
- R&D center**
- Warehouse**
- Jammu - Kashmir
- Himachal Pradesh
- Punjab
- Uttarakhand
- Chandigarh
- Pantnagar
- Haryana
- Delhi
- Uttar Pradesh
- Lucknow
- Rajasthan
- Bihar
- Assam
- Nagaland
- Mizoram
- Manipur
- Meghalaya
- Sikkim
- West Bengal
- Jharkhand
- Orissa
- Chhattisgarh
- Madhya Pradesh
- Gujarat
- Sanand
- Daman and Diu
- Goa
- Karnataka
- Andhra Pradesh
- Telangana
- Maharashtra
- Chakan
- R&D Centre
- Jamshedpur
- Pithampur
- Sricity
- Hosur
- Kerala
- Tamil Nadu
- Puducherry
- Lakshadweep
- Andaman and Nicobar Islands

Strictly Confidential

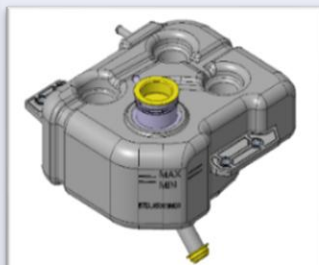
TTR Portfolio

Product Portfolio for ICEV

ICE Application



Radiator



DAT



Engine Cooling System



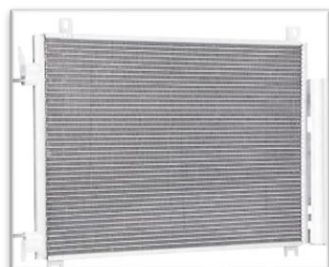
Heater Core



Intercooler



EGR Cooler



Condenser



CRFM



Radiator for 2W



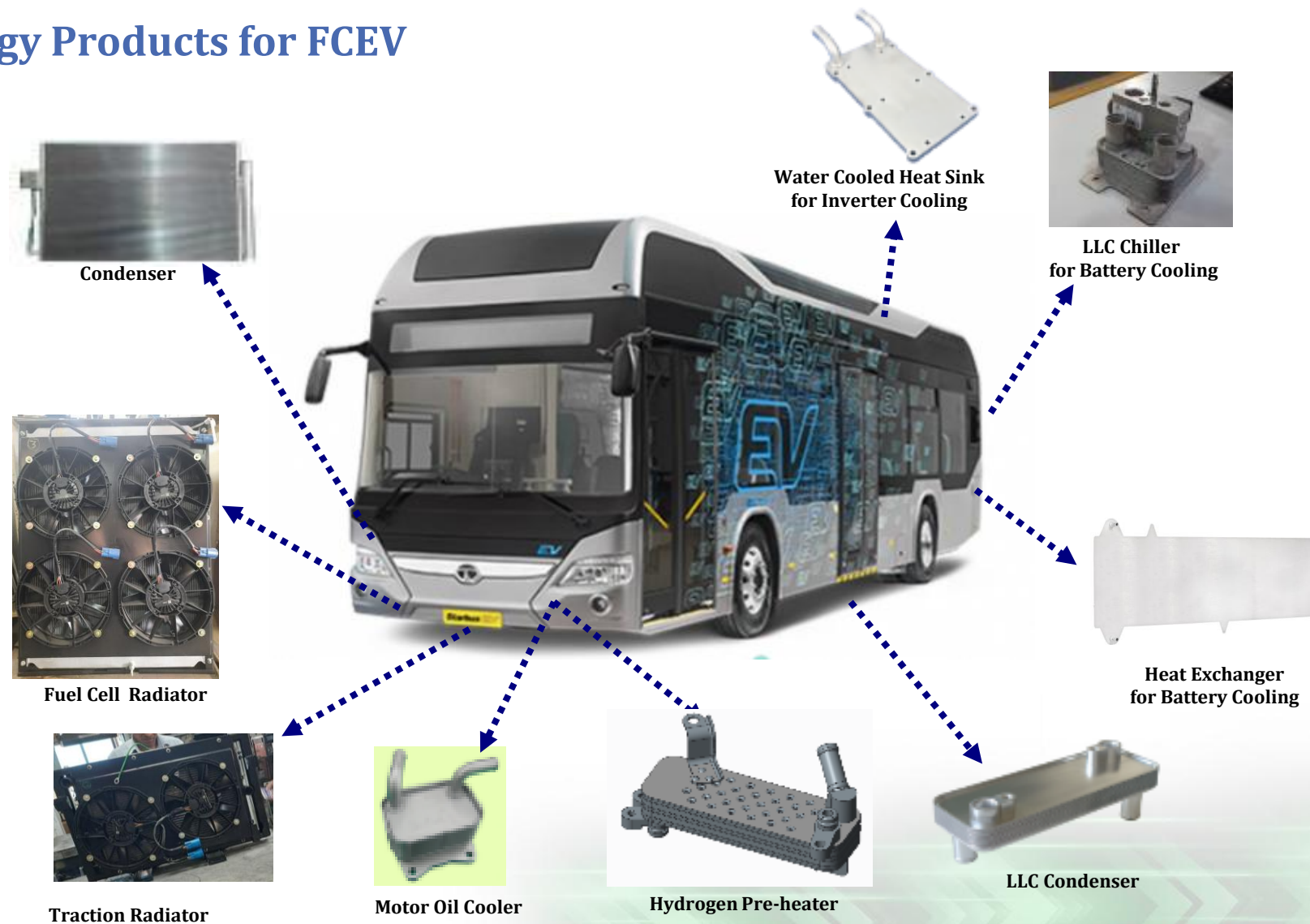
Oil cooler



Transmission Oil cooler

TTR Portfolio

New Technology Products for FCEV



TTR Portfolio

New Technology Products BEV Products



Cooling Systems for Emerging Applications

- TTR is not only providing cooling systems for automotive applications but also for new stationary products in renewable energy sector.
- Applications such as green hydrogen production systems, solar power battery charging systems, solar-powered cold warehouses, etc.



Hydrogen Generation System



Solar Powered Charging Station



Solar Cold Warehouse

TTR Portfolio

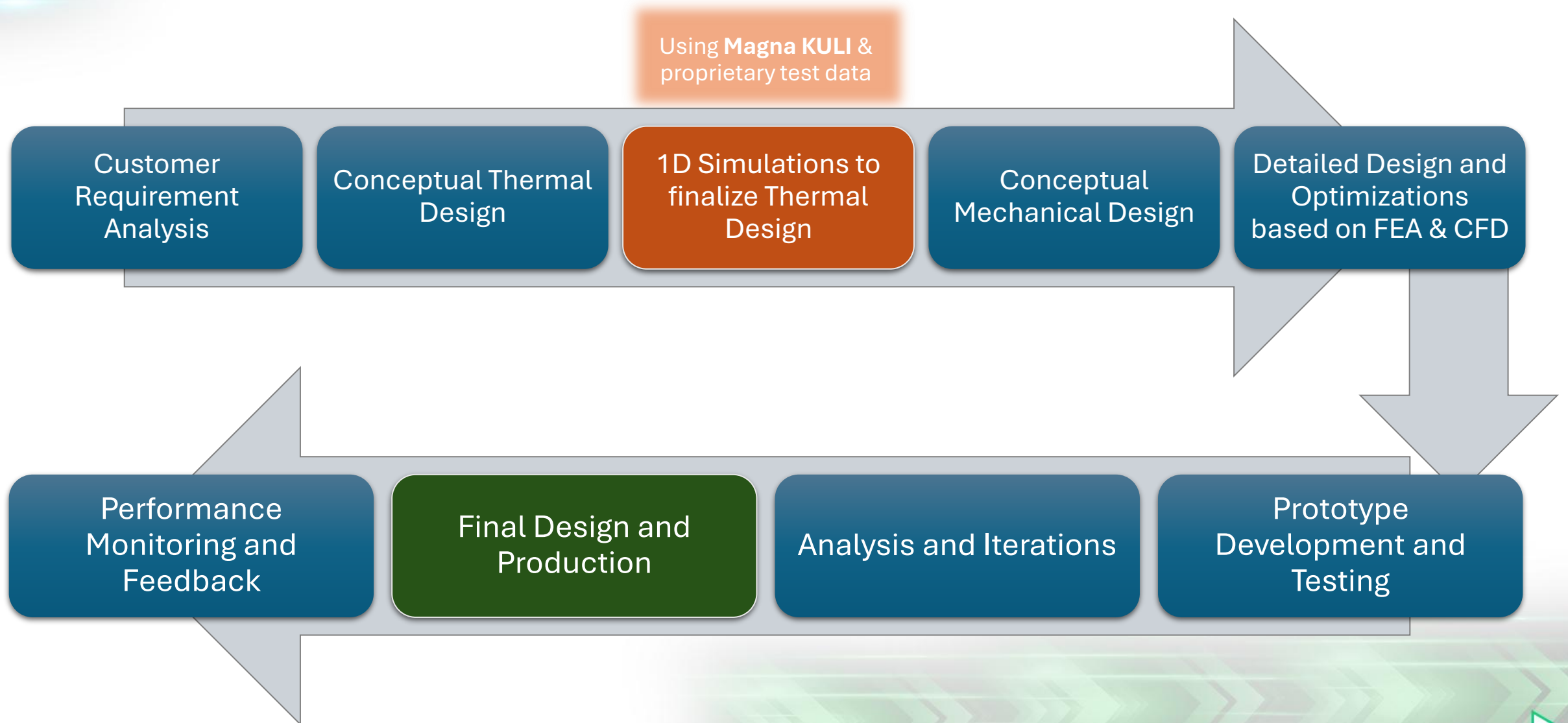
Market Segment	Customers
Passenger Vehicle (PV)	
Medium & Heavy Commercial Vehicle (M&HCV)	
Light Commercial Vehicle (LCV)	
Small Commercial Vehicle (SCV)	
Tractors	
Diesel Genset (DG)	
Two/Three Wheeler (2/3W)	
Aftermarket	75+ Distributors Across India
Export	
Construction Equipment (CE)	

Three blue chevrons pointing left, composed of multiple parallel lines.

TTR Methodology for Heat Exchanger Design

Three green chevrons pointing right, composed of multiple parallel lines.

TTR Methodology for Heat Exchanger Design



1D Simulation Methodology Using KULI

Simulation Overview

Introduction

- Simulation methodology is a technique used to model case study using software to analyze its behavior.
- It helps to experiment with different input conditions.
- By simulating iterations, we can optimize solution for better outcomes.

Steps

- Define the problem.
- Model the system
- Validate and verify

Benefits

- Time Saving
- Cost-Effective
- Decision Support



1D Simulation Methodology Using KULI

KULI Graphical User Interface (GUI)

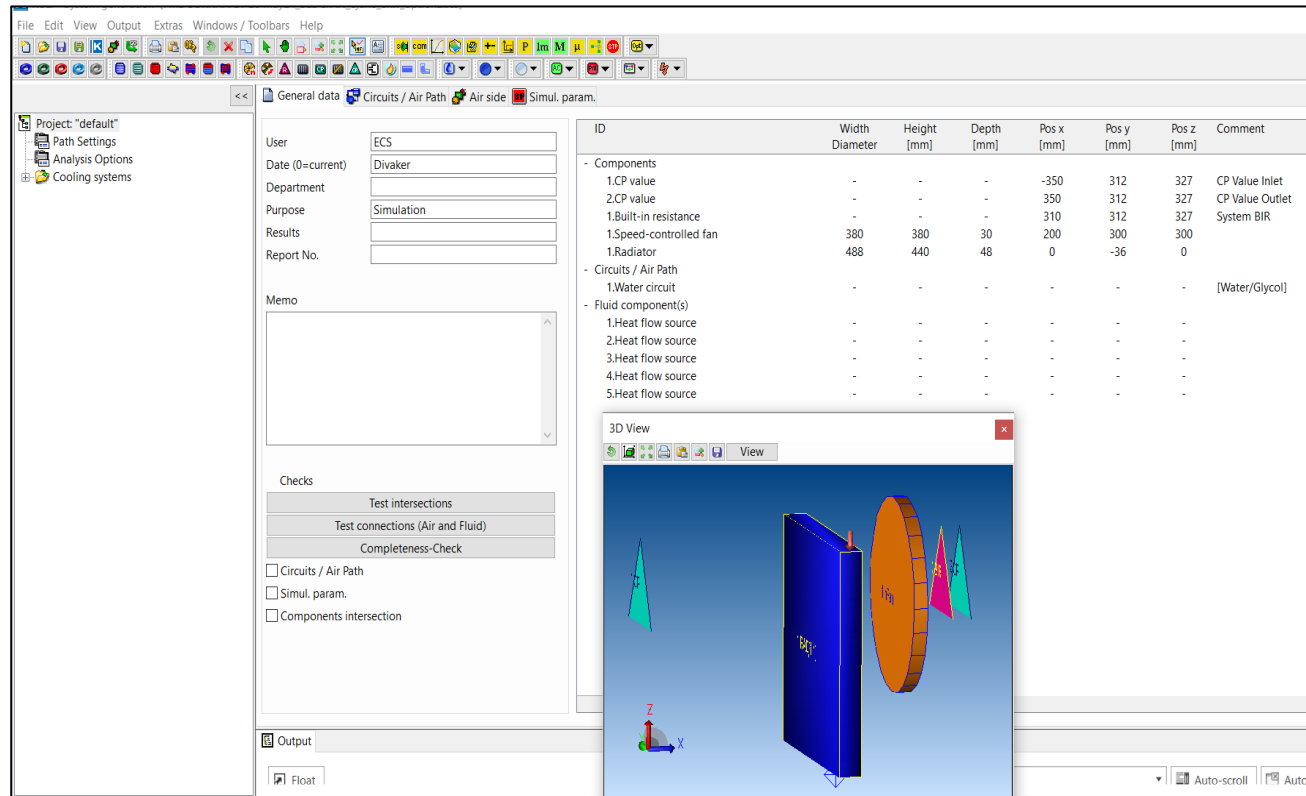


Image : KULI GUI

General Data

All components are displayed here and the dimension, position of all the component can be defined.

Circuit/ Air path

The inner circuit is defined on this tab.

Air side

All components are arranged on this tab according to the direction of airflow.

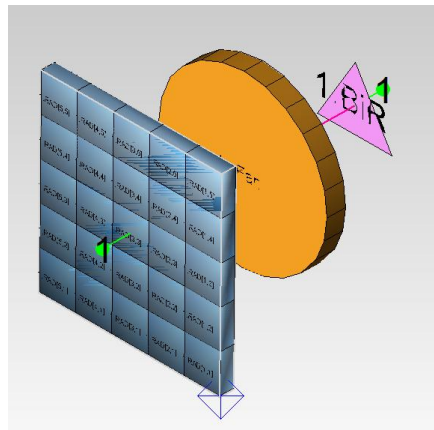
Simulation Parameters

Simulation parameters as per given input conditions can be defined in this section.

1D Simulation Methodology Using KULI

CFD Coupling with Resistance Matrix

- To set up a resistance matrix, a cooling system block must be defined, including all components affecting airflow. One component should be divided into a grid to analyze how uneven airflow impacts its surface.
- In order to consider the influence of a non-uniform air flow in the simulation of a cooling system, air velocity CFD data of the distribution are needed.
- The air velocity distribution is first simulated and stored in a CFD data file, which is then transferred to KULI for thermal performance analysis.
- A resistance matrix is created to map the CFD-derived air velocity onto the radiator surface, after which the thermal simulation is run following the same procedure as in the basic uniform flow case.



KULI Model

Resistance matrix [-7]

File Tools CFD-Data

Resistance matrix

Input data: CFD data set: KULI Resistance matrix

KULI CFD file: kulu2_1.cfd

Comment: 1234

Blocks used for CFD Matrix (e.g. 1;3;4): 1

Ambient air pressure [hPa]: 1013

Ambient temp. [°C]: 45

Air humidity [%]: 50

Unit of field coordinates: m

Modify KULI CFD file...

Position y-direction [mm]: 241

Position z-direction [mm]: 255

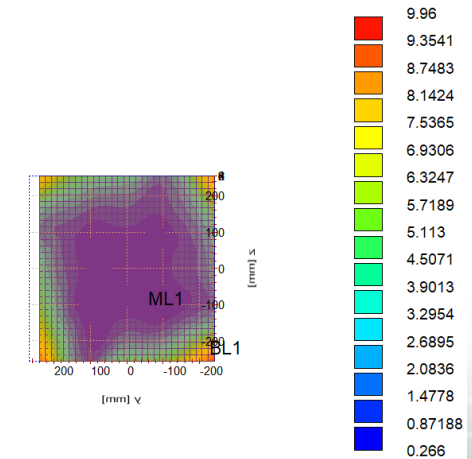
Max. number of shown values: 1000

y-coordinate	z-coordinate	Velocity in x-Direction [m/s]
0.241	0.255	7.6
0.241	0.127	2.83
0.241	0	3.48
0.241	-0.128	5.24
0.241	-0.255	9.2
0.121	0.255	3.92
0.121	0.127	0.79
0.121	0	0.382
0.121	-0.128	0.266
0.121	-0.255	1.44
0	0.255	3.28
0	0.127	0.716
0	0	0.322
0	-0.128	0.439
0	-0.255	3.89
-0.12	0.255	1.97
-0.12	0.127	0.628
-0.12	0	0.551
-0.12	-0.128	0.279
-0.12	-0.255	4.96
-0.241	0.255	8.57

Method: IMEL

Class Limit: Classify X 0

Resistance Matrix Tab



CFD velocity Field

Problem Statement



Problem Statement

- **Problem Statement Leading to Project Initiation:**

- In the cooling trial performed at customer end, engine cooling system on a tractor has failed, leading to overheating issues that compromised engine performance and reliability
- Multiple troubleshooting approaches were attempted to resolve the problem.
- It was noted that the distance between the fan blade and the radiator core significantly impacts the cooling performance.
- A dedicated project was undertaken to evaluate radiator performance at different fan-to-radiator distances under controlled conditions.

- **Objective:**

- To study and quantify the effect of varying the fan-to-radiator distance along with minor shroud design modifications on radiator efficiency and overall cooling performance.

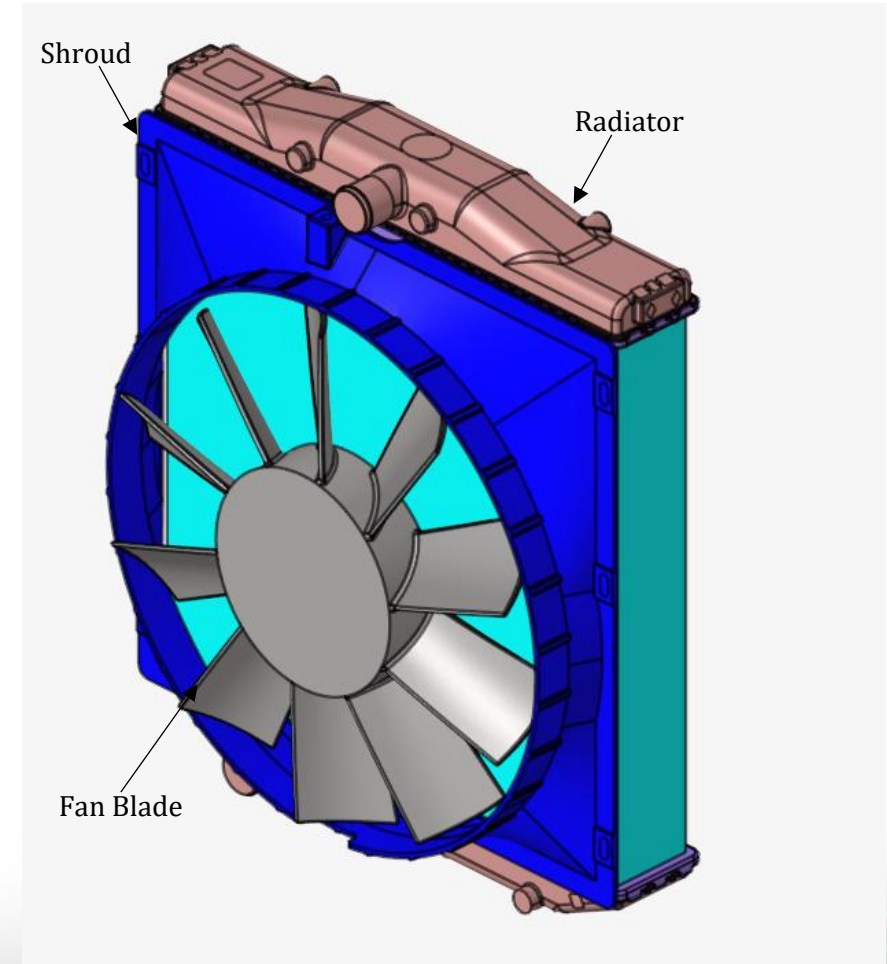


Introduction



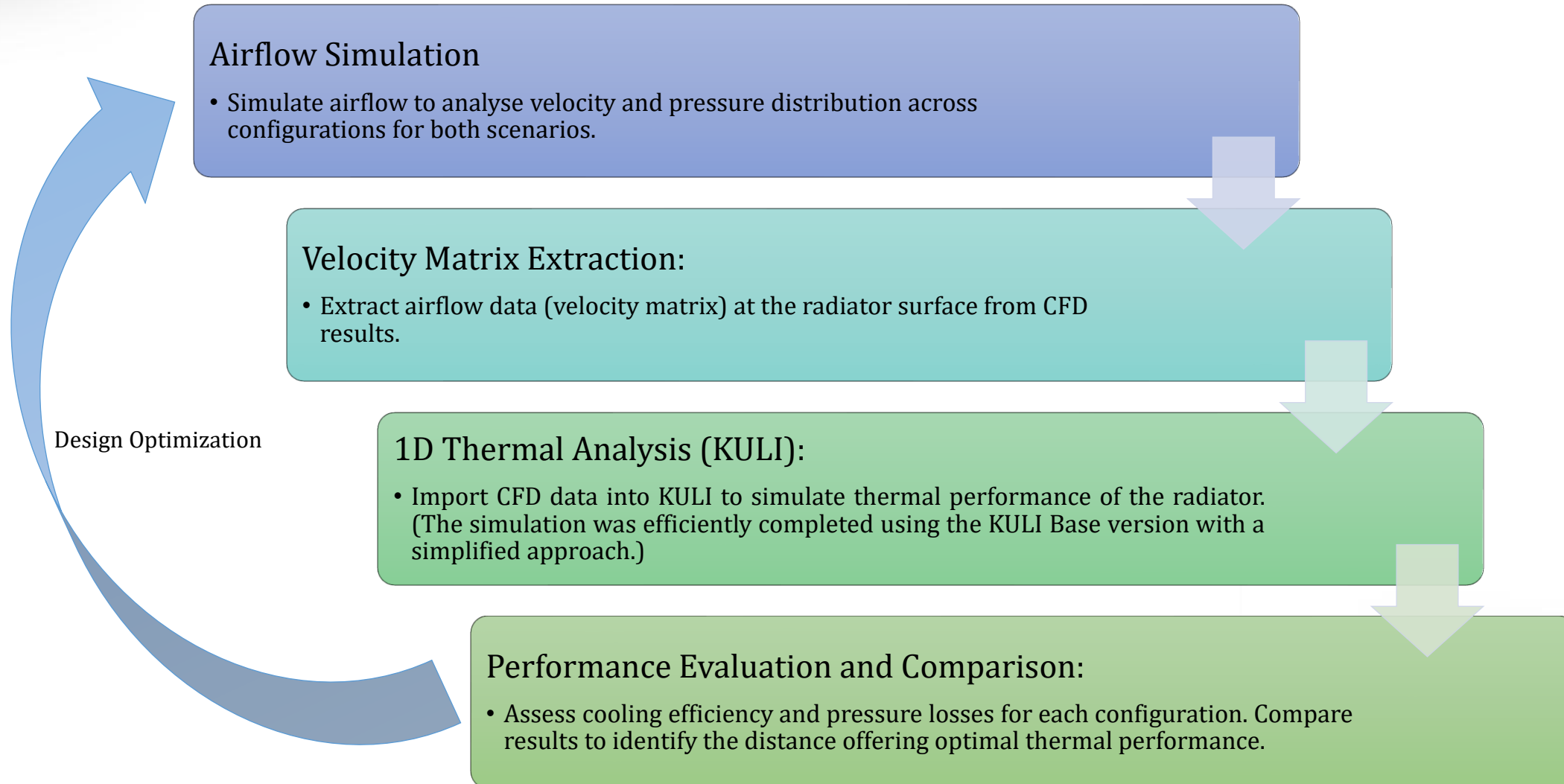
Introduction

- Efficient thermal management is critical for performance and reliability across automotive, off-highway, agricultural, and construction machinery applications.
- Radiator-to-fan spacing significantly influences:
 - Airflow distribution
 - Heat dissipation efficiency
 - System pressure losses
- Packaging constraints often affect optimal spacing in machinery design.
- Simulation-driven approach used to optimise thermal performance:
 - CFD analysis (Acusolve):
 - 1D thermal modeling (KULI):
- To achieve accurate performance prediction, the non-uniform airflow distribution from the CFD results was imported into the thermal model.



Engine Cooling System

Methodology

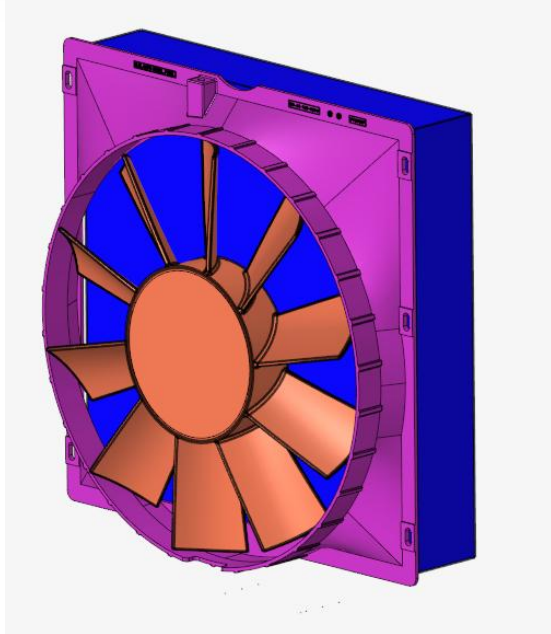


The background features a light blue and white geometric pattern with large, stylized arrows pointing left and right. The left arrow is blue and the right arrow is green.

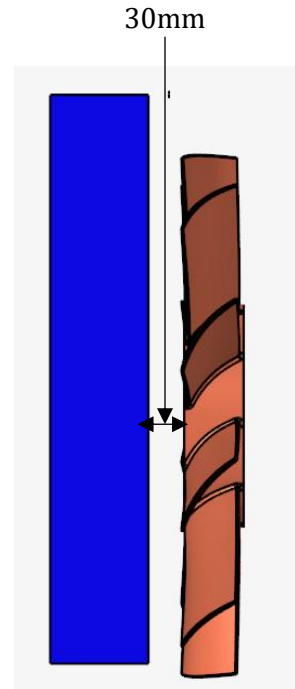
Results and Discussion



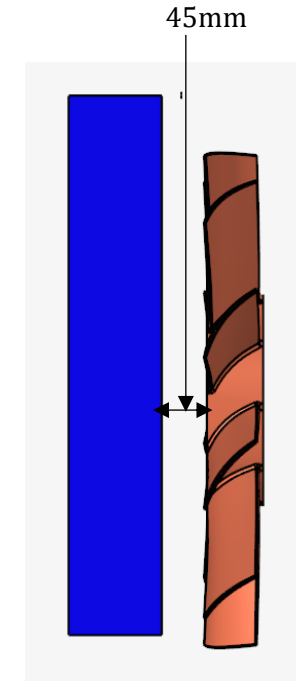
CFD Model



CAD Model for CFD



Existing Packaging



Modified Packaging

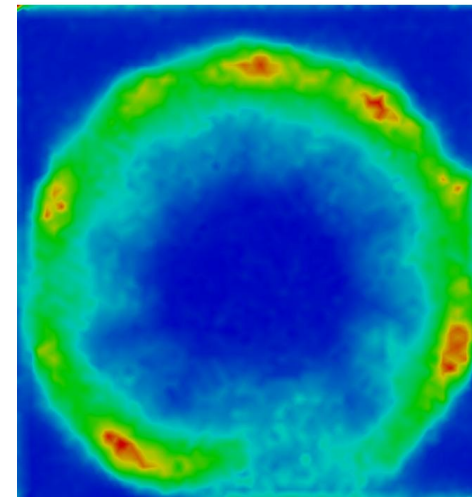
- Above CAD model is used for simulation.
- In the modified package, in addition to changing the distance between the radiator and the fan blade, we have also introduced changes to the shroud design.
- The radiator was simplified as a porous cuboid in the CFD model to replicate airflow resistance realistically while reducing computational complexity.

Results & Discussion

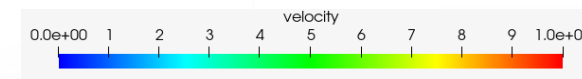
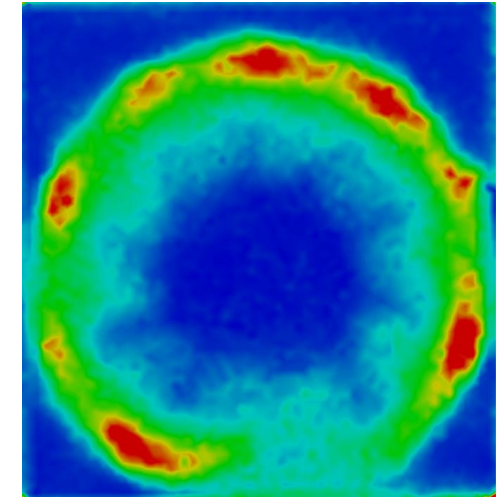
CFD Simulation

- A 30 mm distance between the fan blade and radiator core was used as the baseline configuration.
- An additional 15 mm of available space in the design allowed increasing the fan-to-radiator distance to 45 mm, and also enabled modifications to the shroud design to further optimize airflow.
- At 30 mm spacing, airflow restriction due to the shroud was more significant, leading to less uniform flow and increased recirculation zones.
- At 45 mm spacing, airflow was more evenly distributed, with a more prominent high-velocity zone across the radiator surface.
- By increasing the distance between the fan and the radiator, along with implementing modifications to the shroud design, the average air velocity improved by approximately 6%.
- From this airflow simulation, entry air velocity profiles across the radiator surface were extracted for use in subsequent thermal analysis.

30mm Radiator Fan Blade
Distance



45mm Radiator Fan Blade
Distance



Result & Discussion

Velocity Matrix

			30mm Radiator Fan Blade Distance	45mm Radiator Fan Blade Distance
X (m)	Y (m)	Z (m)	X- Direction Air Velocity (m/s)	X- Direction Air Velocity (m/s)
0.241	0.255	-0.037	7.6	8
0.241	0.127	-0.037	2.03	2.3
0.241	0.000	-0.037	3.48	3.67
0.241	-0.128	-0.037	5.24	5.7
0.241	-0.255	-0.037	9.2	9.8
0.121	0.255	-0.037	3.92	4.2
0.121	0.127	-0.037	0.79	0.86
0.121	0.000	-0.037	0.382	0.402
0.121	-0.128	-0.037	0.266	0.286
0.121	-0.255	-0.037	1.44	1.56
0.000	0.255	-0.037	3.28	3.4
0.000	0.127	-0.037	0.716	0.75
0.000	0.000	-0.037	0.322	0.34
0.000	-0.128	-0.037	0.439	0.45
0.000	-0.255	-0.037	3.89	4.1
-0.120	0.255	-0.037	1.97	2.14
-0.120	0.127	-0.037	0.628	0.66
-0.120	0.000	-0.037	0.551	0.58
-0.120	-0.128	-0.037	0.279	0.3
-0.120	-0.255	-0.037	4.96	5.2
-0.241	0.255	-0.037	8.57	8.9
-0.241	0.127	-0.037	3.56	3.75
-0.241	0.000	-0.037	2.45	2.62
-0.241	-0.128	-0.037	2.13	2.28
-0.241	-0.255	-0.037	9.96	10.2

Simplified Approach



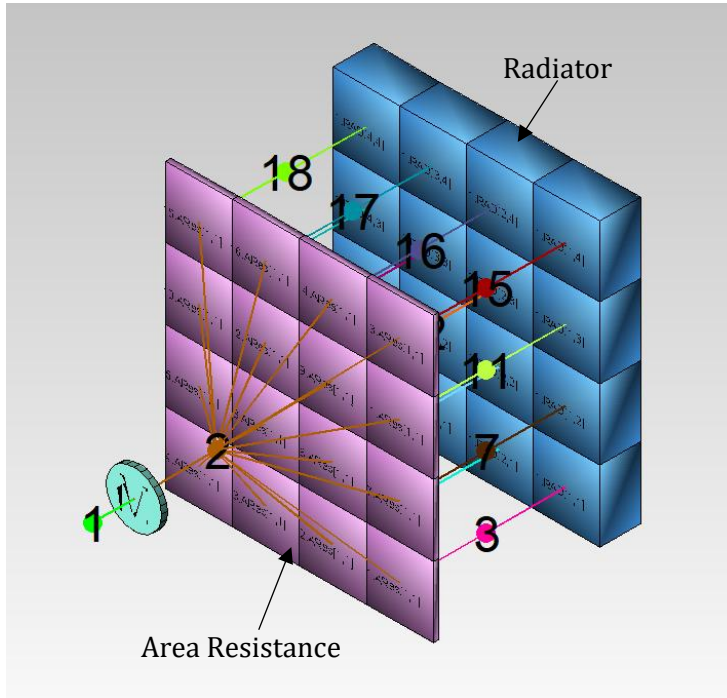
- In the absence of the KULI Advanced license, the simulation was effectively carried out using the KULI Base version by adopting a simplified yet practical approach, applying non-uniform airflow across the radiator via area resistance.
- The radiator core is divided into 16 equal parts to analyze airflow distribution.
- A total of 25 nodes are assigned across the core surface to capture air velocity data.
- For each of the 16 parts, the average air velocity is calculated using the finite difference method.

Air Velocity Matrix (30mm Radiator Fan Blade Distance)			
3.68	1.65	2.18	3.59
1.80	0.55	0.55	1.67
1.35	0.40	0.35	2.34
4.33	2.39	1.51	4.04

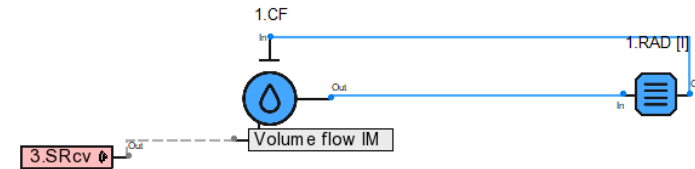
Air Velocity Matrix (45mm Radiator Fan Blade Distance)			
3.86	1.74	2.30	3.84
1.90	0.58	0.59	1.81
1.45	0.42	0.37	2.51
4.50	2.51	1.60	4.34



KULI Model



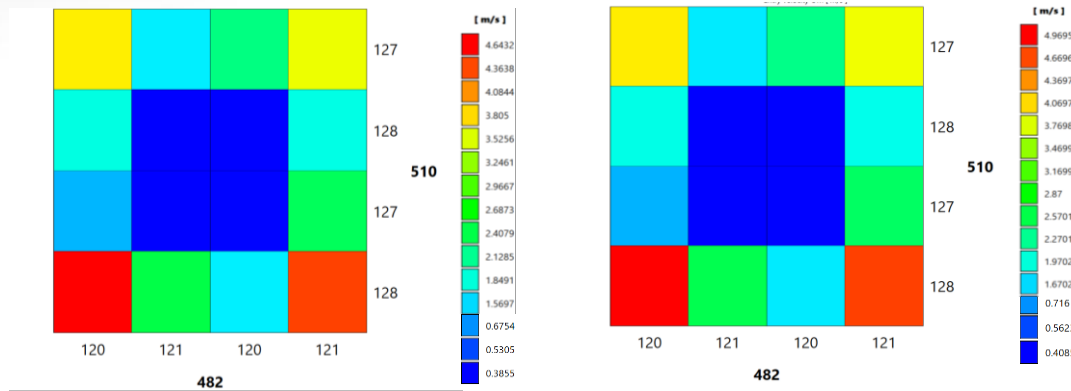
3D View



Cooling Circuit

Result & Discussion

KULI Simulation



30mm Radiator Fan Blade Distance

45mm Radiator Fan Blade Distance

Parameters	Units	Iteration 1 (30mm Radiator Fan Blade Distance)	Iteration 2 (45mm Radiator Fan Blade Distance)
Ambient Temperature	°C	45	45
Maximum Allowable Coolant Inlet Temperature	°C	110	110
Coolant Flow rate	LPM	45	45
Mean Exit Speed	m/s	2.3	2.5
Coolant Heat Rejection	kW	26.5	28

- At 30 mm spacing:
 - Airflow across radiator was non-uniform with low-velocity zones.
 - Resulted in lower heat rejection and lower overall thermal efficiency.
- At 45 mm spacing:
 - More uniform airflow distribution observed across radiator face.
 - Led to higher average air exit speed, enhancing convective heat transfer.
 - Resulted in 5.7% improvement in heat rejection and lower coolant outlet temperature.
 - Confirms benefit of improved airflow uniformity on thermal performance.
 - Despite a slight increase in system volume at 45 mm, the pressure drop remained within acceptable limits.
- Confirms that even small changes in spacing and shroud design can have measurable impact on thermal performance.



Three blue chevrons pointing left, composed of multiple parallel lines.

Conclusion & Future Scope

Three green chevrons pointing right, composed of multiple parallel lines.

Conclusion & Future Scope

- Optimized fan-to-radiator distance (45 mm) and shroud design significantly improved thermal performance.
- A 6% increase in average airflow velocity from the optimized configuration due to more uniform airflow, resulting in a 5.7% improvement in heat rejection.
- Lower coolant outlet temperatures and enhanced heat transfer efficiency.
- CFD and KULI simulation integration provided accurate predictions of airflow and thermal behavior, validating design choices.
- Despite a slight increase in system volume, the pressure drop remained manageable, making the 45 mm spacing a viable solution.
- Key takeaway: Proper radiator-fan distance optimization enhances overall system efficiency, leading to better engine cooling .

- Future Scope:
 - Utilize the extracted resistance matrix from CFD simulations to model airflow behavior more accurately in future KULI analyses.
 - Future design considerations should include precise airflow optimization to maximize cooling performance while minimizing pressure losses





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