

COOLING CONCEPTS FOR A FAMILY OF SMALL, HEAVY-FUEL ROTARY ENGINES FOR USE IN AUXILIARY POWER UNITS

GVSETS

A Select History the Rotary Engine

POWER AND MOBILITY

Early Development	Various rotary pumps, compressors, and steam engines
1959	Successful demonstration of NSU-Wankel rotary engine
1964	Introduction of rotary-powered sports car, the NSU Spider
1970's	Curtiss-Wright multi-fuel rotary engine research
1971	Mazda RX-3 rotary coupe
1978	Maxda RX-7 sports car
1980's	John Deere multi-fuel rotary engine
2001	Mazda RX-8 sports car
2005	L-3 begins heavy-fuel rotary engine development

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

A Variety of Applications

POWER AND MOBILITY



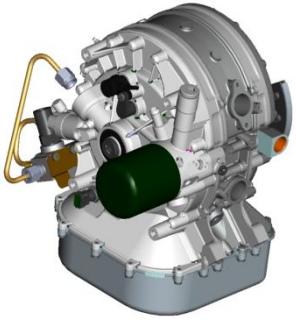
















This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

The L-3 Combat Propulsion Systems Rotary Engine Family

POWER AND MOBILITY

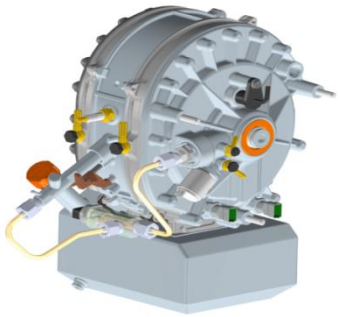
- High Power Density
- Operates on Heavy Fuel
  - JP-8
  - DF-2
  - Jet A
- 350cc, 45 hp per rotor
- One- or Two-Rotor configurations
- High pressure direct injection
- Spark-assisted ignition
- Turbocharged and aftercooled



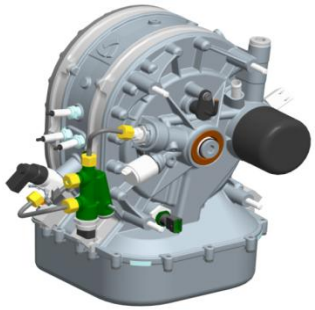
This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

R350 Engine Series Evolution

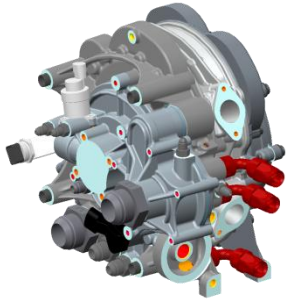
- A-Series
  - Initial evaluation of basic design concepts
- B-Series
  - Packaged oil system accessories onto the engine
  - Increased engine efficiency through changes in injector and spark plug location
  - Improved manufacturability and assembly
  - Currently on test
- C-Series
  - More robust structure
  - Improved cooling (water)
  - High speed PTO for Accessories, (starter/generator, pump)
  - Dry sump



R351 A-Series



R351 B-Series



R351 C-Series

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

Rotary Engine Thermal Challenges

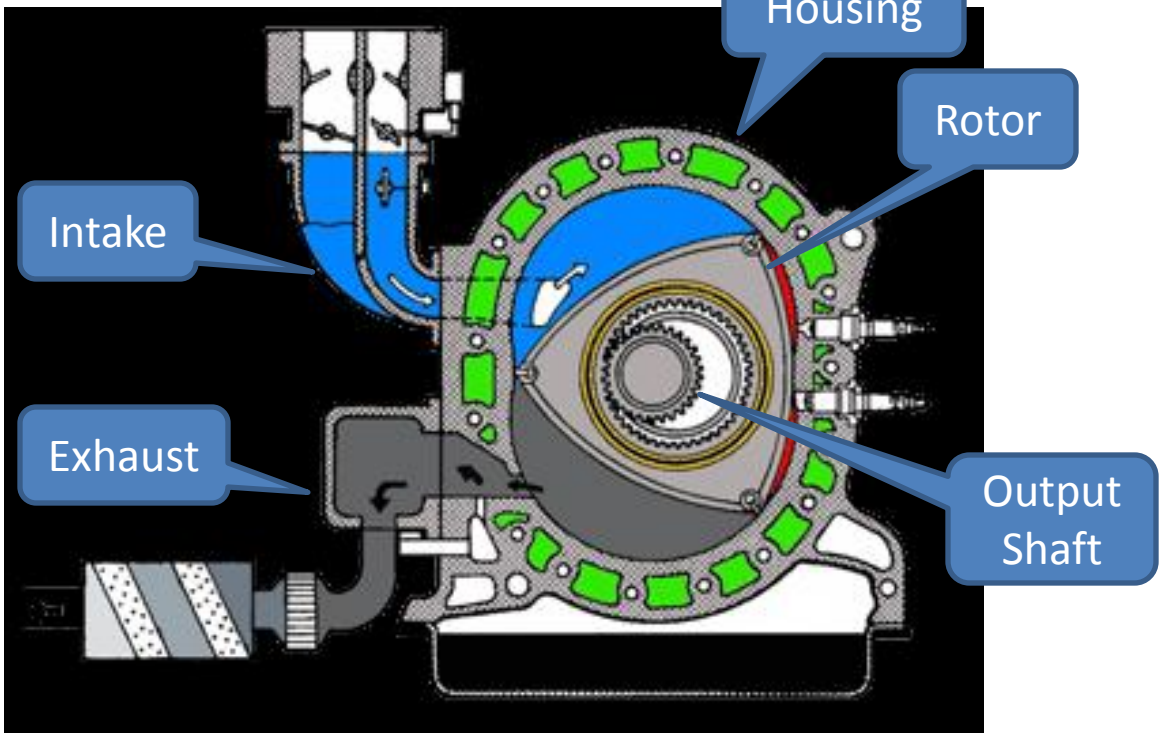
- Four-Stroke Piston Engine
  - The combustion chamber is alternately exposed to hot combustion gasses and cool intake gasses
- Rotary Engine
  - The rotor housing is continuously exposed to combustion gasses in one location and intake gasses in another
  - Higher localized metal temperatures
  - Higher thermal gradient

Michigan Chapter NDIA National Defense Industrial Association

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

GVSETS

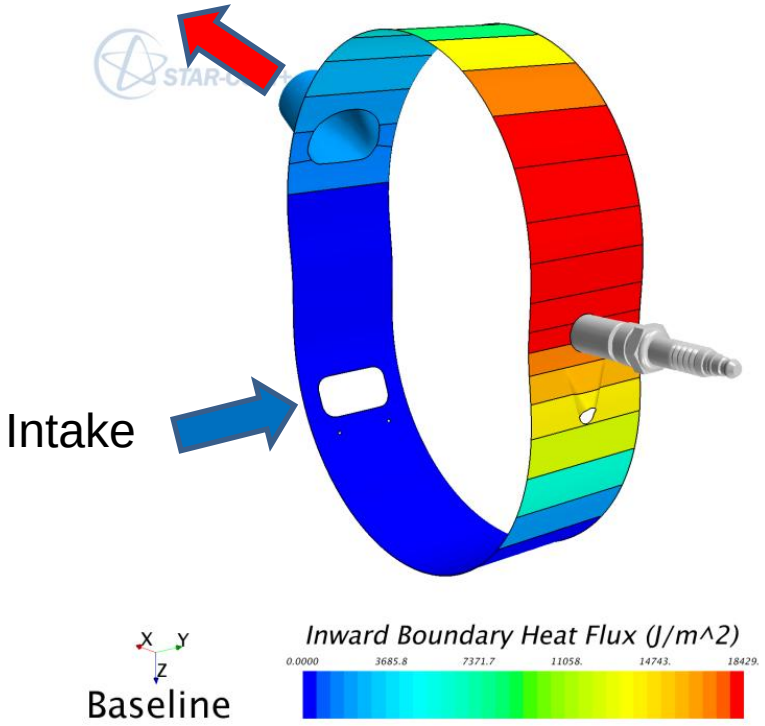
Rotary Engine Basic Components

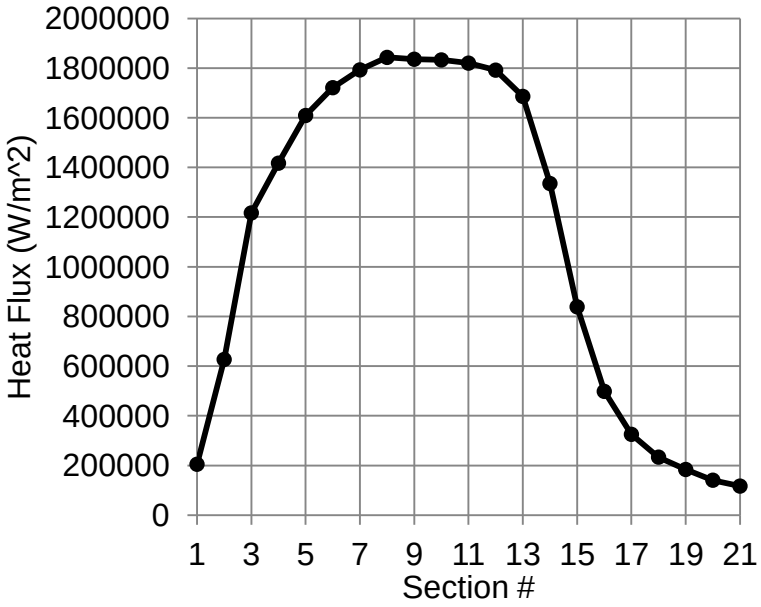


This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

Thermal Conditions Around the Housing

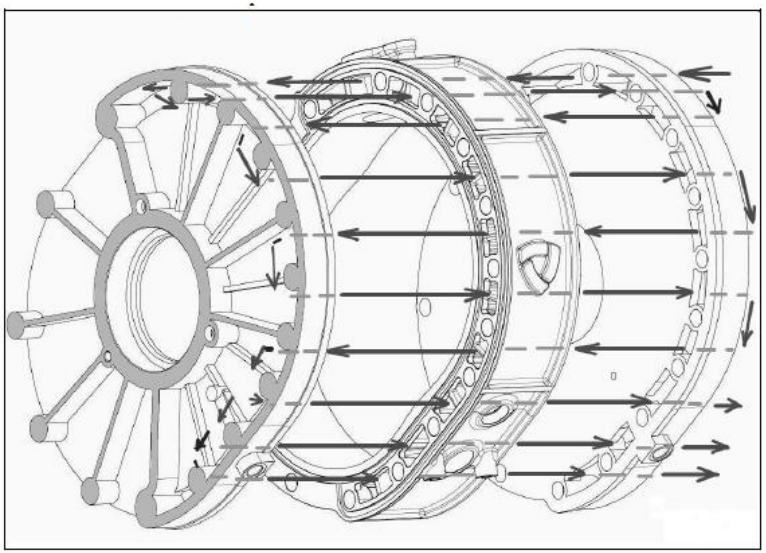
Exhaust

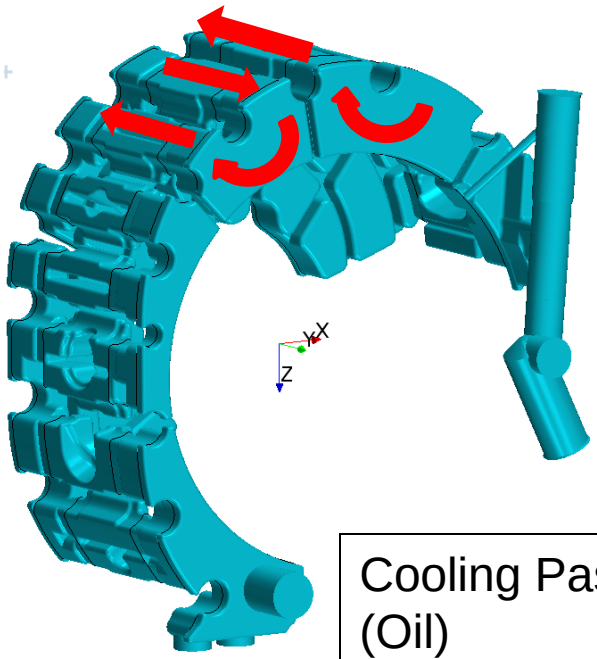




This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

Cooling Oil Flow Pattern

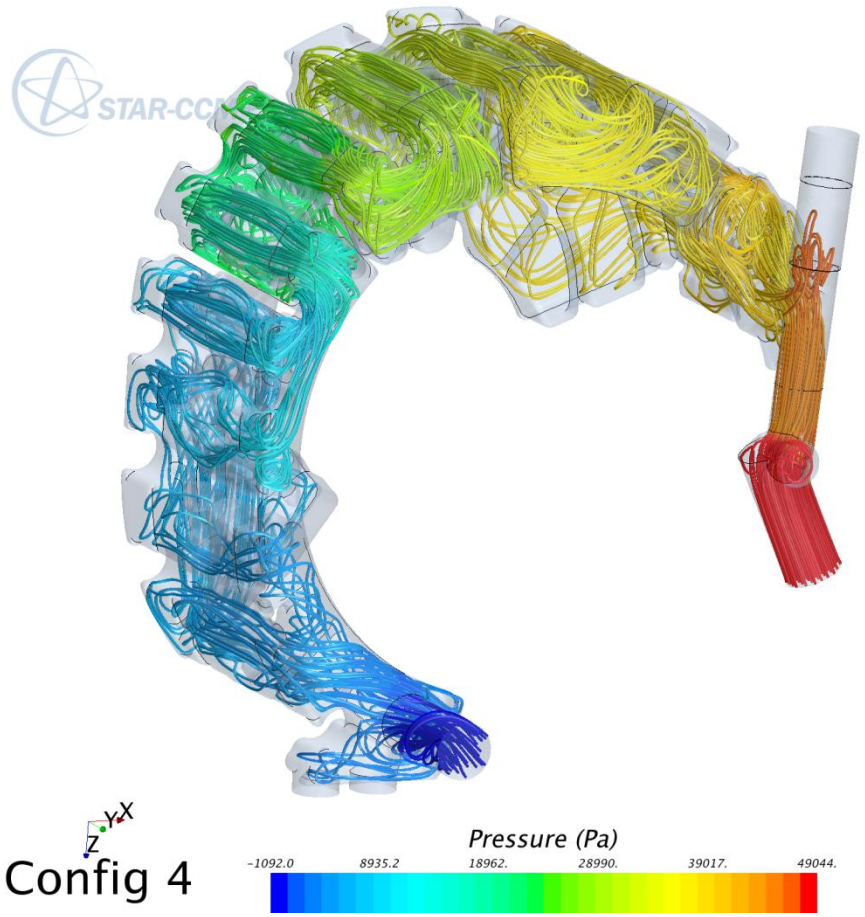




Cooling Passage Core (Oil)

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

Cooling Core – Streamlines Showing Pressure

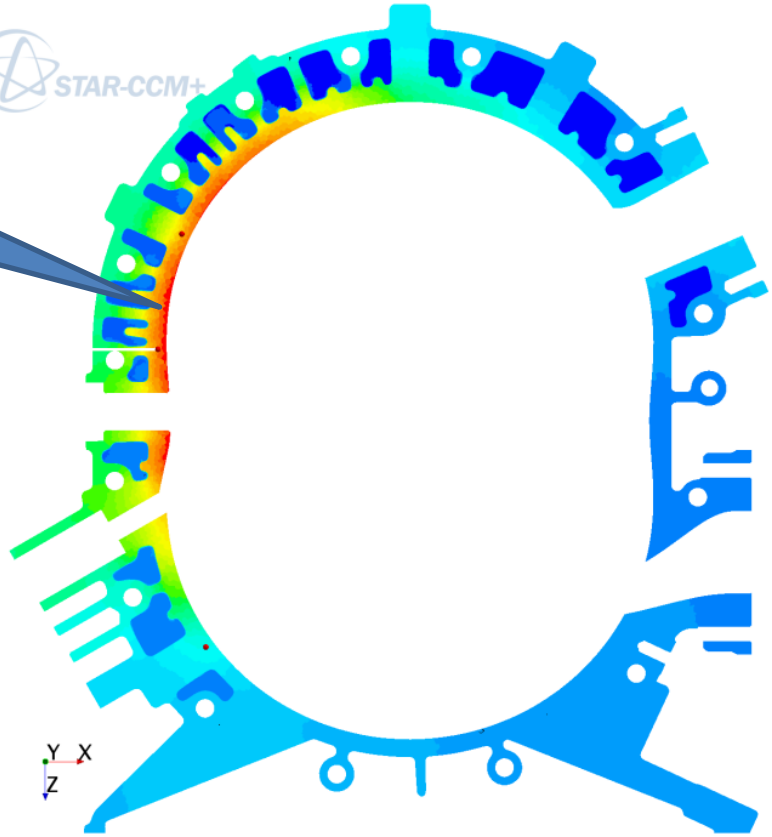


This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

Metal Temperature Prediction
Oil Cooled Housing

POWER AND MOBILITY

Calculated Max Temperature 427°C



Inlet Temp (°C)	Flow Rate (L/min)
75	30

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

Thermal Properties

Fluid	Thermal Conductivity
Fresh Engine Oil	0.145 W/m K
Fresh Water	0.609 W/m K
Water-Ethylene-Glycol	0.410 W/m K

The thermal conductivity of WEG is almost three times better than oil

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

C-Series Water-Cooled Housing

Core Slide

POWER AND MOBILITY

- Design Objectives
  - Move from oil-cooled housing to water-cooled to reduce metal temperatures
  - Create more robust structure for side housing
    - Fretting of side housing observed
    - FEA indicated inadequate transfer of bolt clamp load due to lack of stiffness

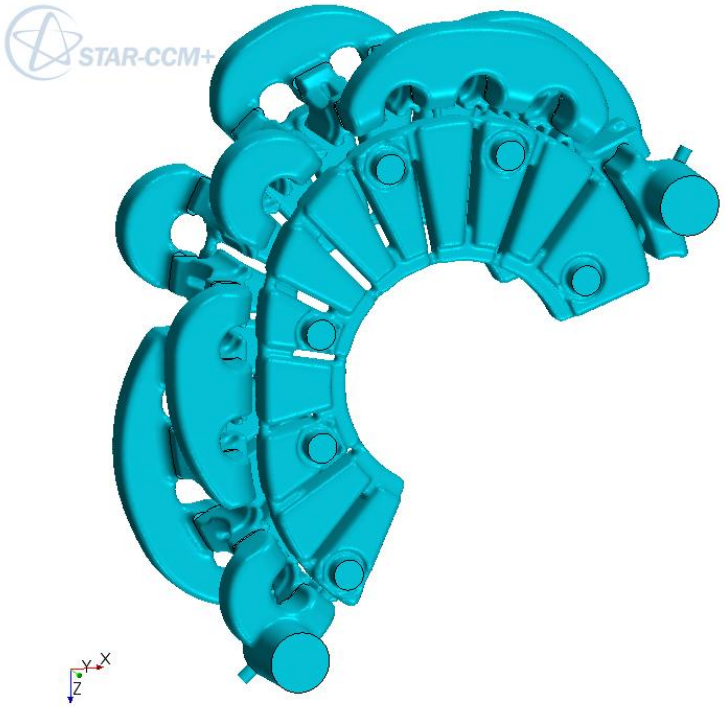
Design Targets

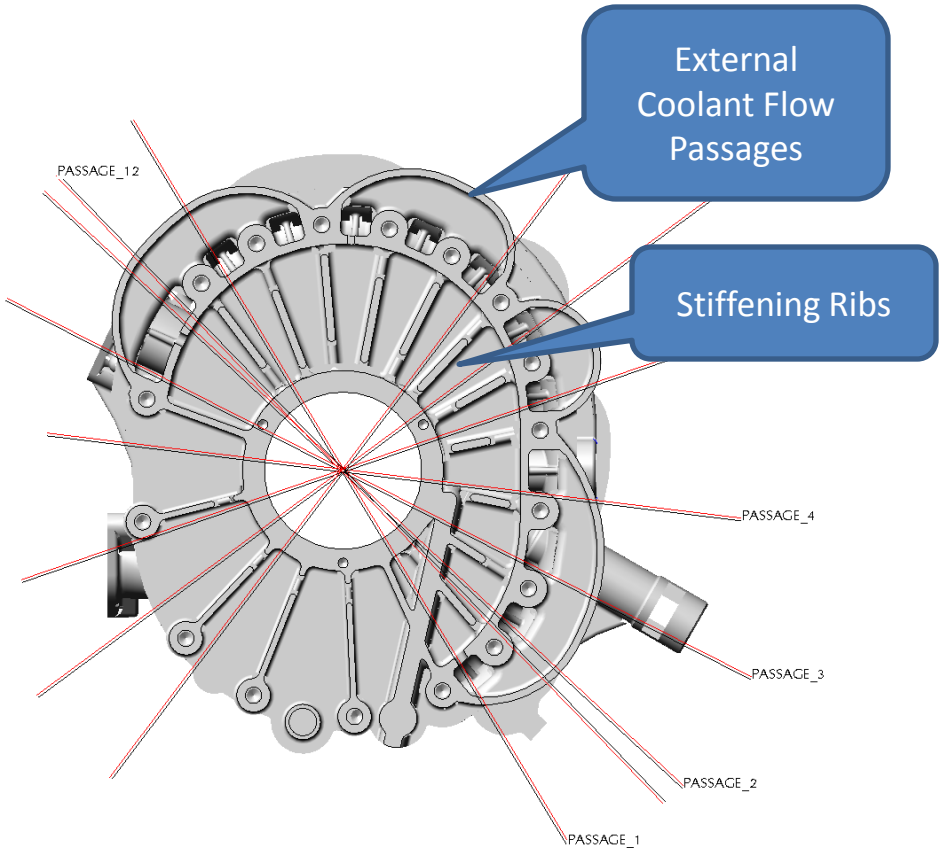
Specification	Oil Cooled Version	Water Cooled Version	
		Water Cooler	Oil Cooler
Fluid	15W-40 Oil	50-50 WEG	15W-40 Oil
Heat Rejection	34 kW	25 kW	9 kW
Flow Rate	46 Liter/min	30 Liter/min	7 Liter/min
Cooler Inlet Temp	123 C	115 C	140 C
Cooler inlet Pressure	30 psig	30 psig	80 psig
Cooler Pressure Drop	15 psig	15 psig	15 psig

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

Water Passages

- New cores were designed to create water passages in the side covers and rotor housing



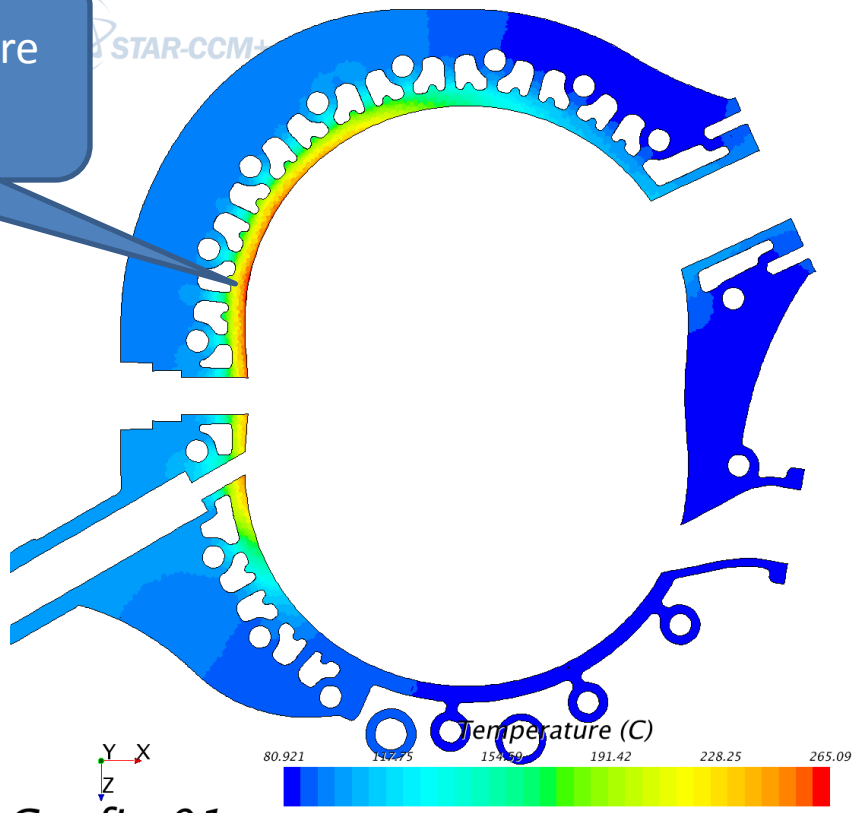


This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

Results with Water Cooling

Metal Temperatures

Predicted temperature reduction of 162°C



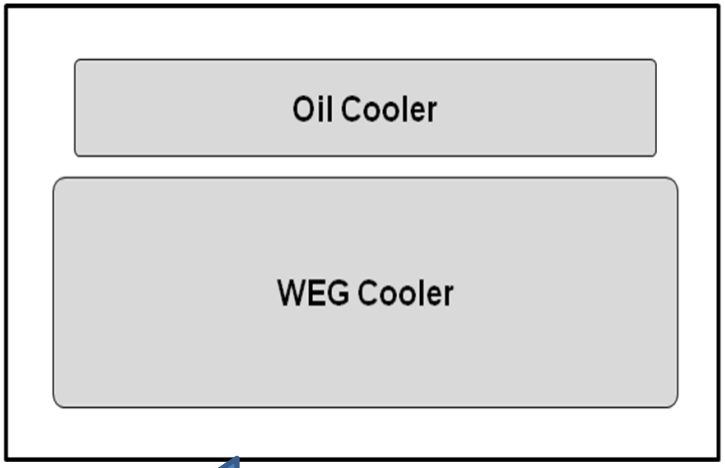
Config 01

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

Heat Exchanger Packaging Requirements

WEG cooling is more effective, resulting in smaller and lighter heat exchangers

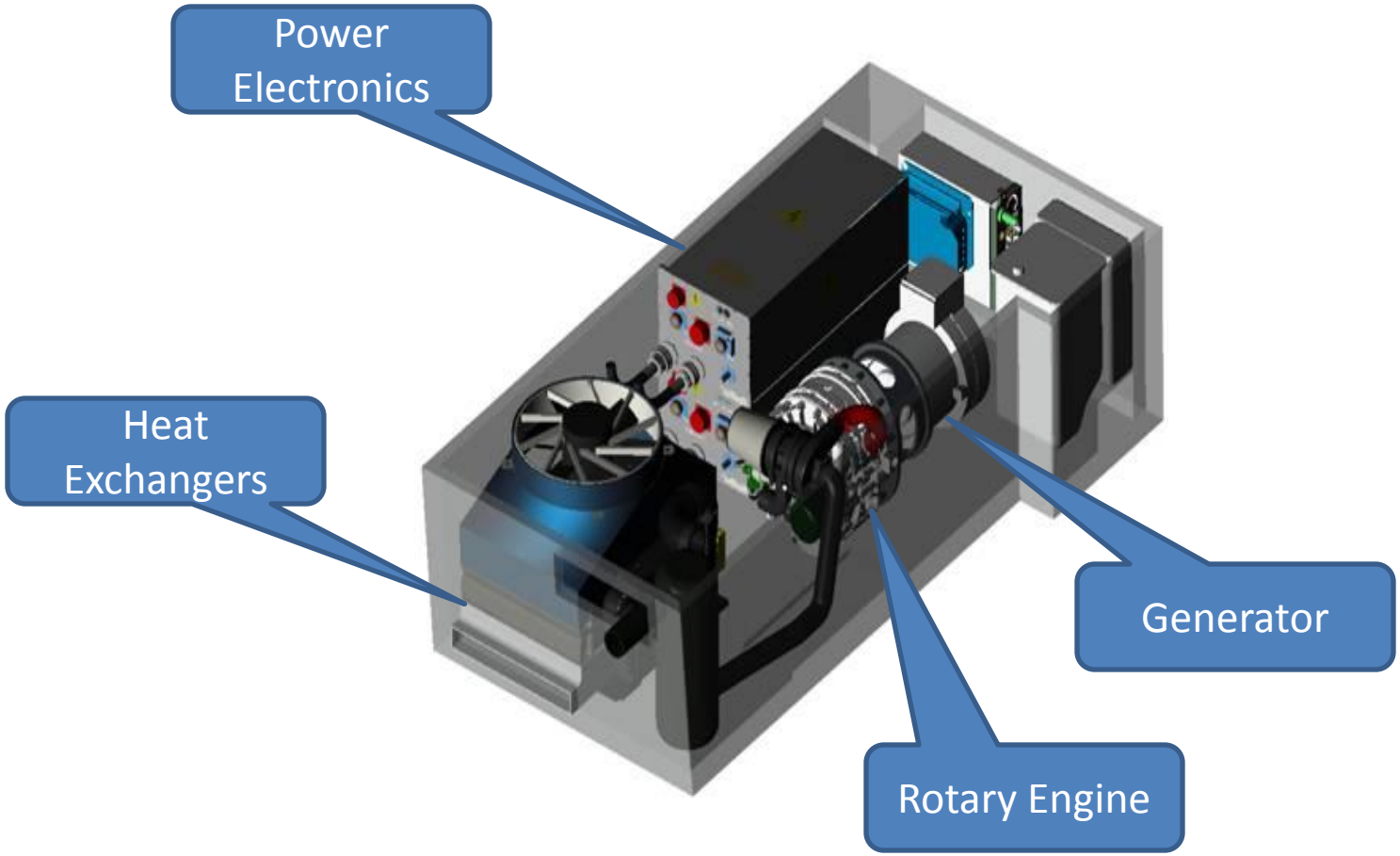
Description	Percent Change Relative to Oil-Cooled Concept
Height	-32%
Width	-16%
Thickness	+7%
Total Volume	**-13%**
Cooler Dry Weight	-45%
Liquid Volume	+70%
Liquid Weight	+110
Total Wet Weight	**-28%**



Cross-Section of Abrams APU Compartment

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

APU Packaging Concept



This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

Summary

- Rotary engines offer significant packaging advantages due to their inherent high power density
- Rotary engines have unique cooling challenges
- Rotary engines can be cooled by either oil or water (WEG)
- WEG is a better cooling media than oil
- The benefits of WEG cooling outweigh the added complexity of a second liquid cooling system

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.

- Thank you!

This document consists of general capabilities information that is not defined as controlled technical data under ITAR Part 120.10 or EAR Part 772.