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Formula SAE Cooling System Design and Optimization

Authors:
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Formula SAE Cooling System Design and Optimization

Submitted to: Dr. Stephen Smith

The Senior Design Project Committee
Drexel University Formula SAE Senior Advisory Board
Department of Mechanical Engineering and Mechanics
Drexel University

Team Number: MEM-T01

Team Members:

Christopher M. Downs	Mechanical Engineering
Gary Auer	Mechanical Engineering

Submitted in partial fulfillment of the requirements for the Senior Design Project

November 24, 2003

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List of Figures* (Figures include HT schematic, schematic of engine and cooling systems with sensor placement included, frame diagram to show allotted space for implementation, diagram of system setup, rough cut specs)

List of Tables* (Type of sensors a dimensions and price, catalog cuts of all sensors and other materials, project management (schedules, GHANTT Chart), excel data sheet, procedure outline, deliverables by term, budget, impact / ethics (societal and environmental), table of resources, safety)

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* Optional component

Drexel Racing Senior Design 2003 Project Proposal

Project Name: MEM-T01 Formula SAE Cooling System Design and Optimization

Project Advisor: Dr. Stephen Smith

i. Project Abstract:

Using a systems engineering approach to engine cooling design we will develop a cooling system that will provide reliable powertrain operation under all vehicle operating conditions. This will include vehicle operation from a cold start to full throttle. Our vehicle will be capable of completing a 16 mile race without overheating. Customer requirements and expectations, business and project requirements, and external requirements will all be identified in the systems partitioning phase of our project. This will allow our team to properly identify all external factors that need to be taken into consideration for our design. Ideal function, control factors, noise factors, side effects, and potential failure modes coupled with external requirements will allow for most optimal design to be attained.

During our testing procedure (see Appendix N) we will utilize a Land and Sea Dynamometer to simulate an appropriate vehicle load. A system of fans, and heaters will also be used to simulate various driving and ambient conditions. A grid of sensors will be placed at various locations on the engine (see Figures 1-3) to acquire all data needed for design. After all relevant information is obtained we will make the proper correlations between any relevant fields of data. This analysis will allow our team to properly size the radiator / fan unit, water pump, header tank, swirl pot, hose diameters, clamps, and overflow. The principles of heat transfer, fluid dynamics, and thermodynamics will be applied.

ii. Introduction

A. Problem Background

One of the three main failures of a Formula SAE race car at competition is engine overheating. This is caused by an improper application/sizing of the radiator(s), the radiator fan(s), the coolant lines, or a combination of all three. The goal of our senior design team will be to optimize a race car cooling system not only based on the ability to cool the car, but also reliability, cost, and ease of manufacture. The cooling system will also have to be designed around a factor of safety in which under worse case scenarios, the car will complete a 16 mile race without overheating.

B. Problem Statement

The Drexel Formula SAE Car is utilizing a Honda F4i 600cc motor as the main component of our vehicle. While a Honda 600cc motor comes equipped with a standard cooling system, this system will not be adequate for our application. Through a careful evaluation of this engine, by use of manufacturer specifications, rough-cut calculations, and system partitioning, (see Appendices A-M) we will be able to properly evaluate all modes of heat transfer and develop a system that is adequate for our application.

C. Constraints to Solution

The constraints to our solution include; variable system configuration (see Appendix R), noise factors, side effects, examination of failure modes, and control factors (see Appendices B-M. Through testing and analysis (Appendix N), we will be able to determine optimal configuration of our system within our constraints.

iii. Statement of Work

A. Method of Solution

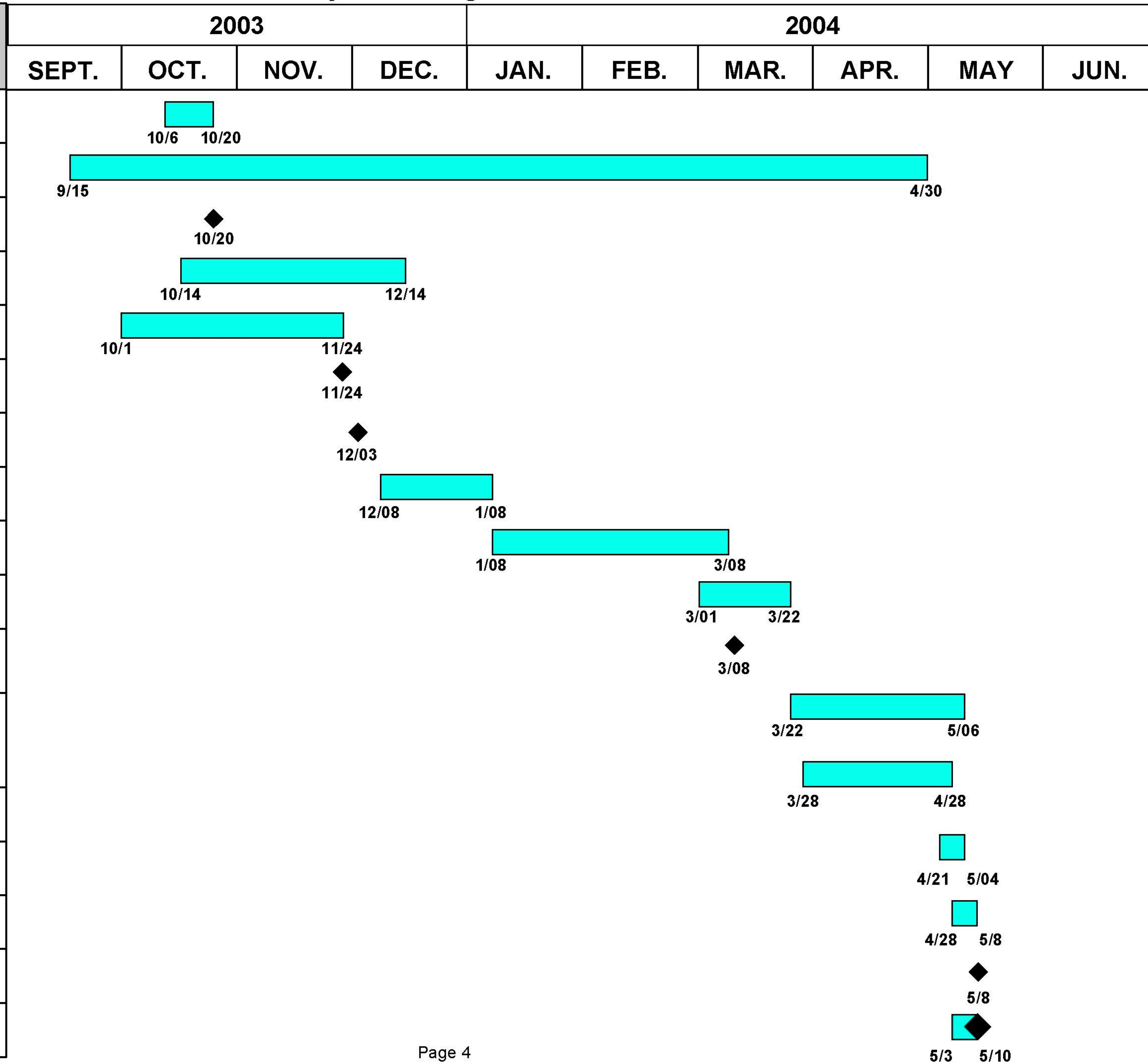
We have chosen to take a systems engineering approach in our design. This layered approach breaks the components of our design into subsystems (see Appendices A-M), where they can be easily evaluated. After evaluating all constraints we will begin our testing procedure (see Appendix N), and make any correlations needed.

B. Alternative Solutions

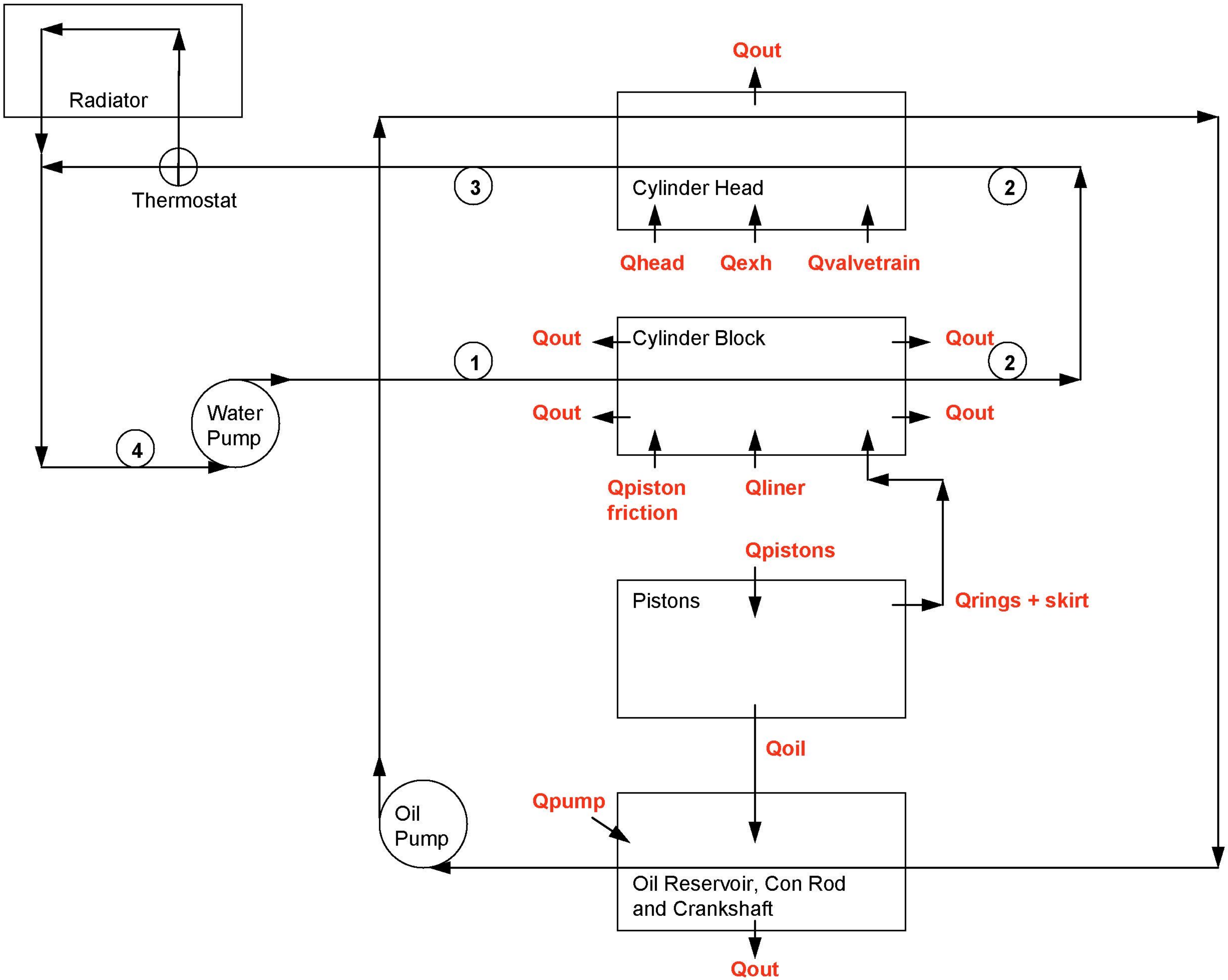
The alternatives to our solution include variable system configuration (see Appendix R)

iv. Project Management Timeline

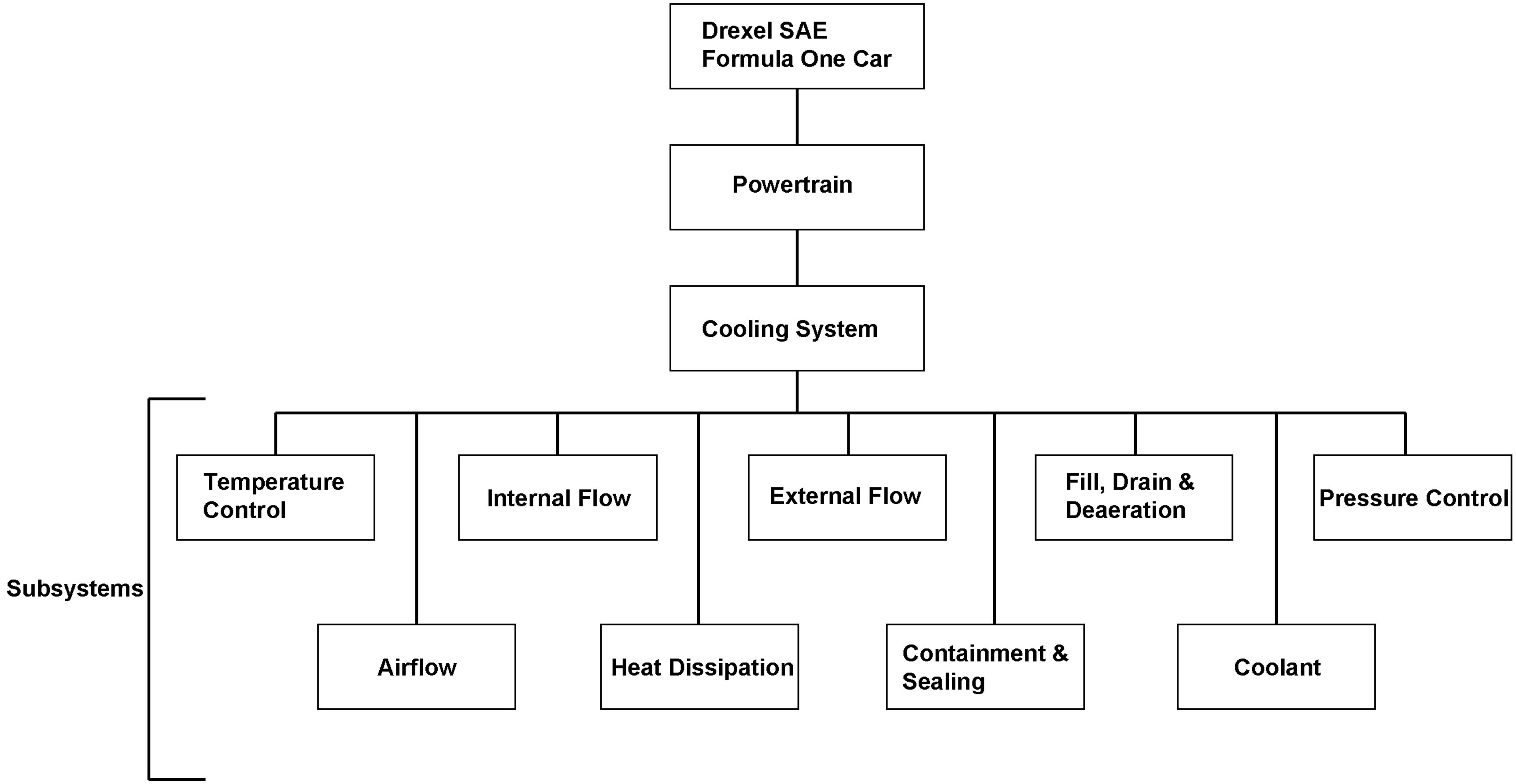
Activity	Dur. (wk.)
Find Advisor	2
Research	30
Pre-proposal Sub.	0
Model System	8
Develop Proposal	7
Proposal Submission	0
Presentation	0
Testing and Rating	4
Review and Analysis	8
Production Planning	3
Progress Report	0
Order Components / Design and Manufacture	6
Construction	4
Design Testing	1.5
Design Modification	1.5
Project Completion	0
Summary Report	1



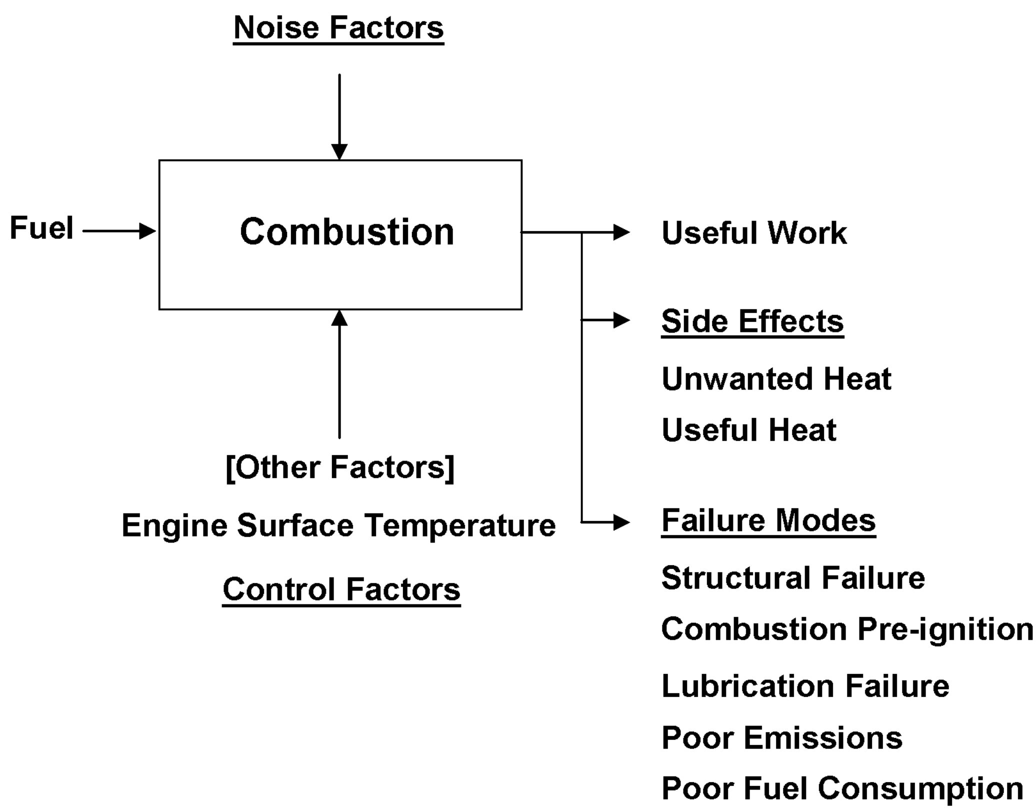
Heat Transfer



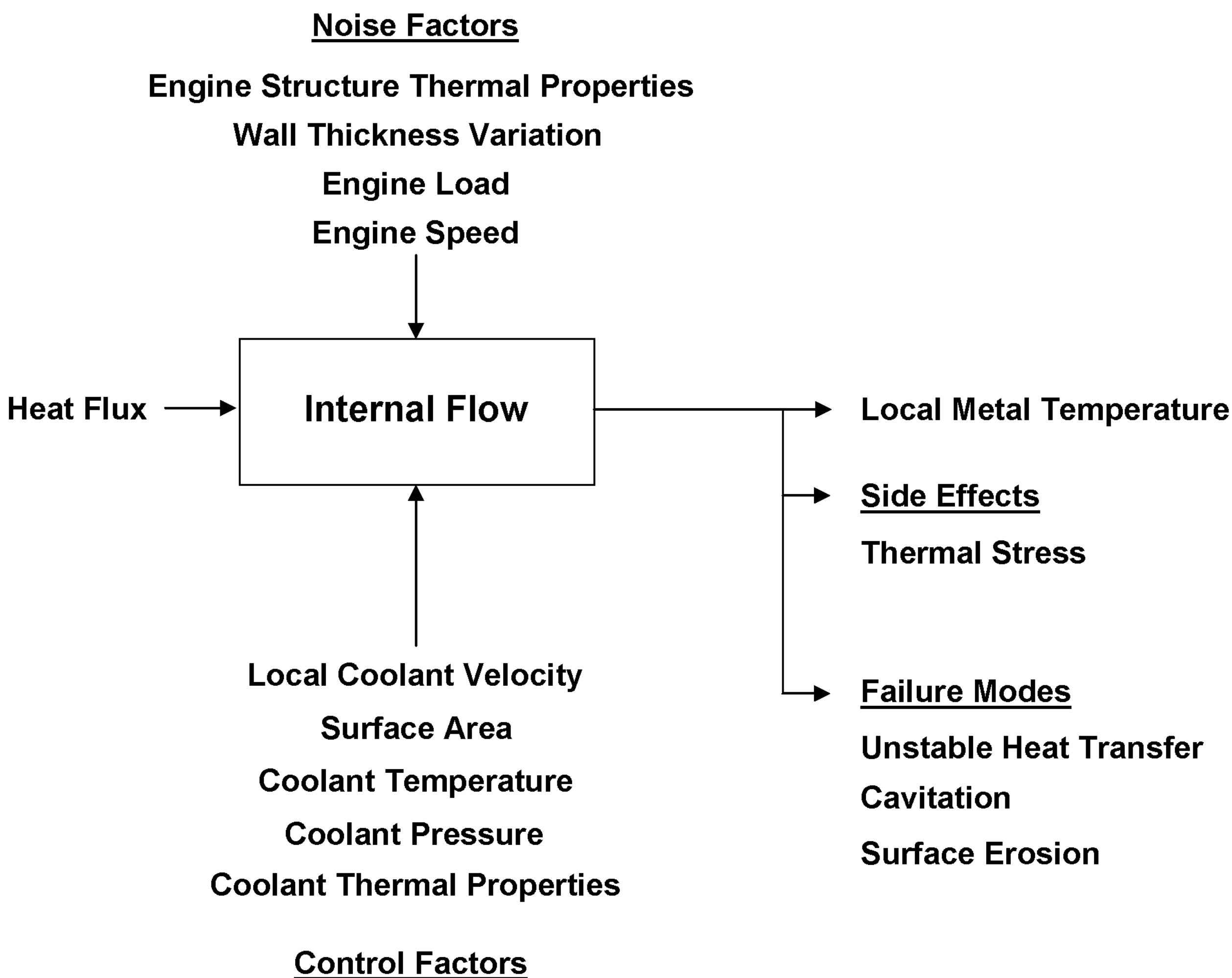
Appendix A - System Partitioning / Task Tree



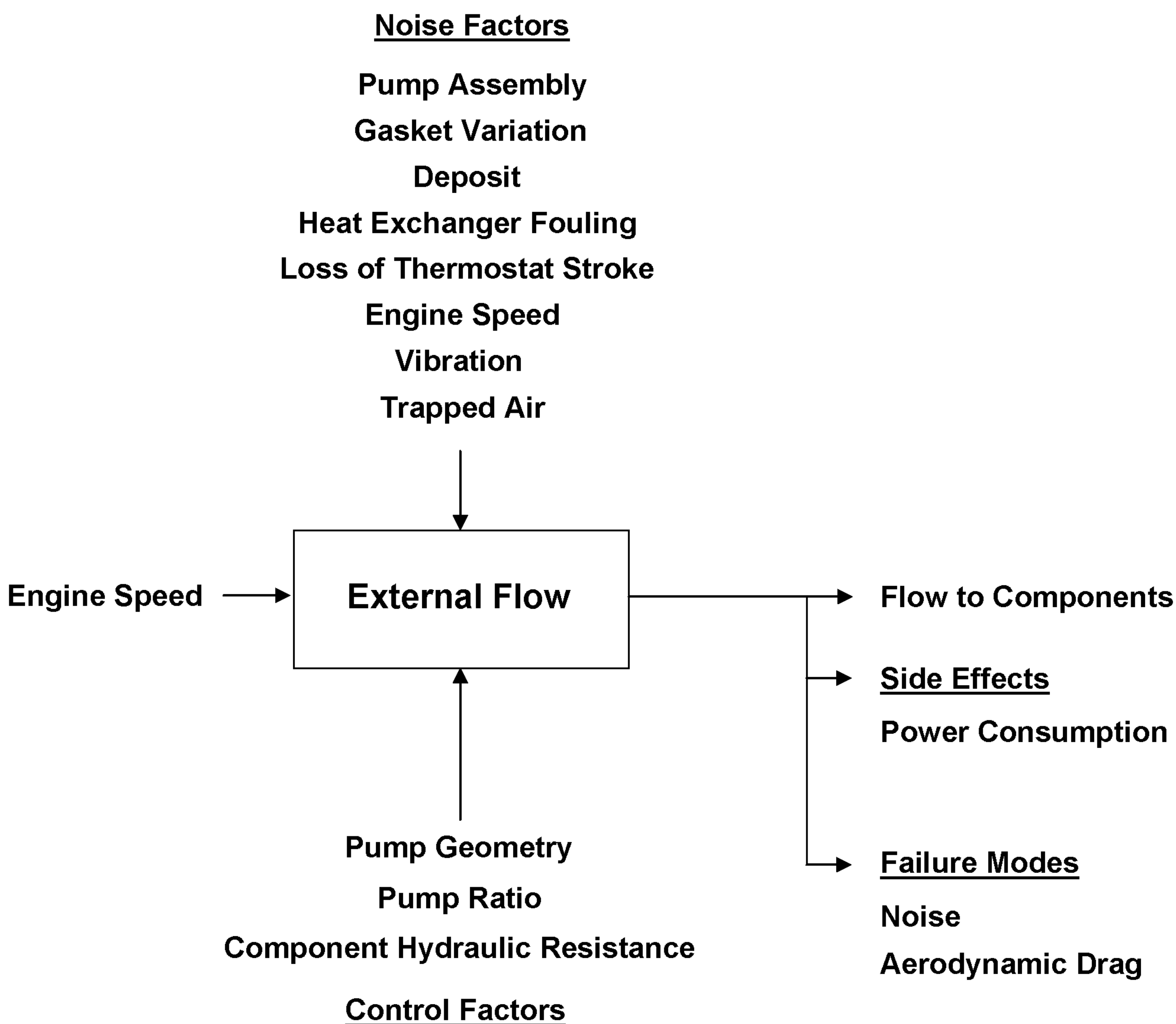
Appendix B - Powertrain Requirements



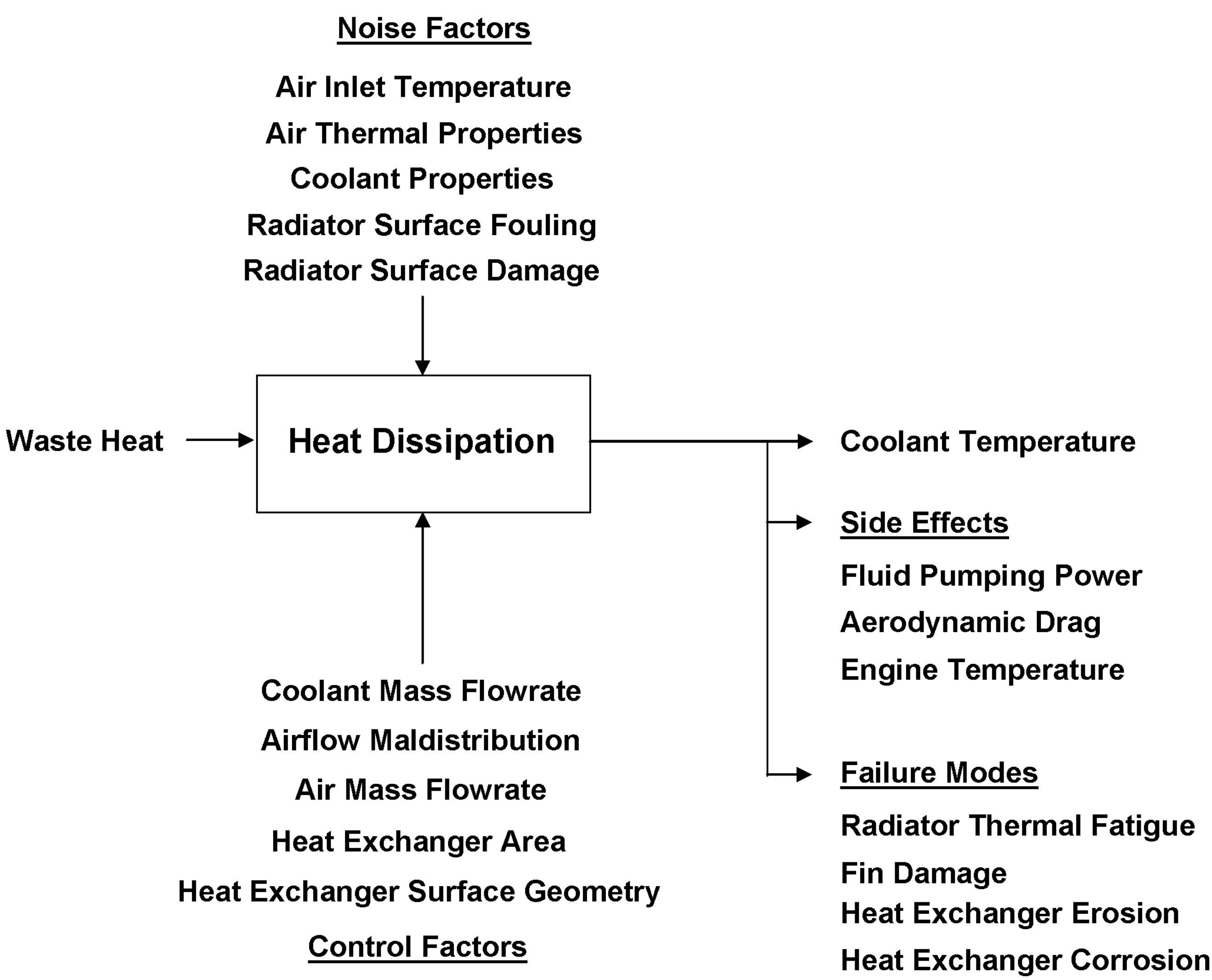
Appendix C - Internal Flow Subsystem



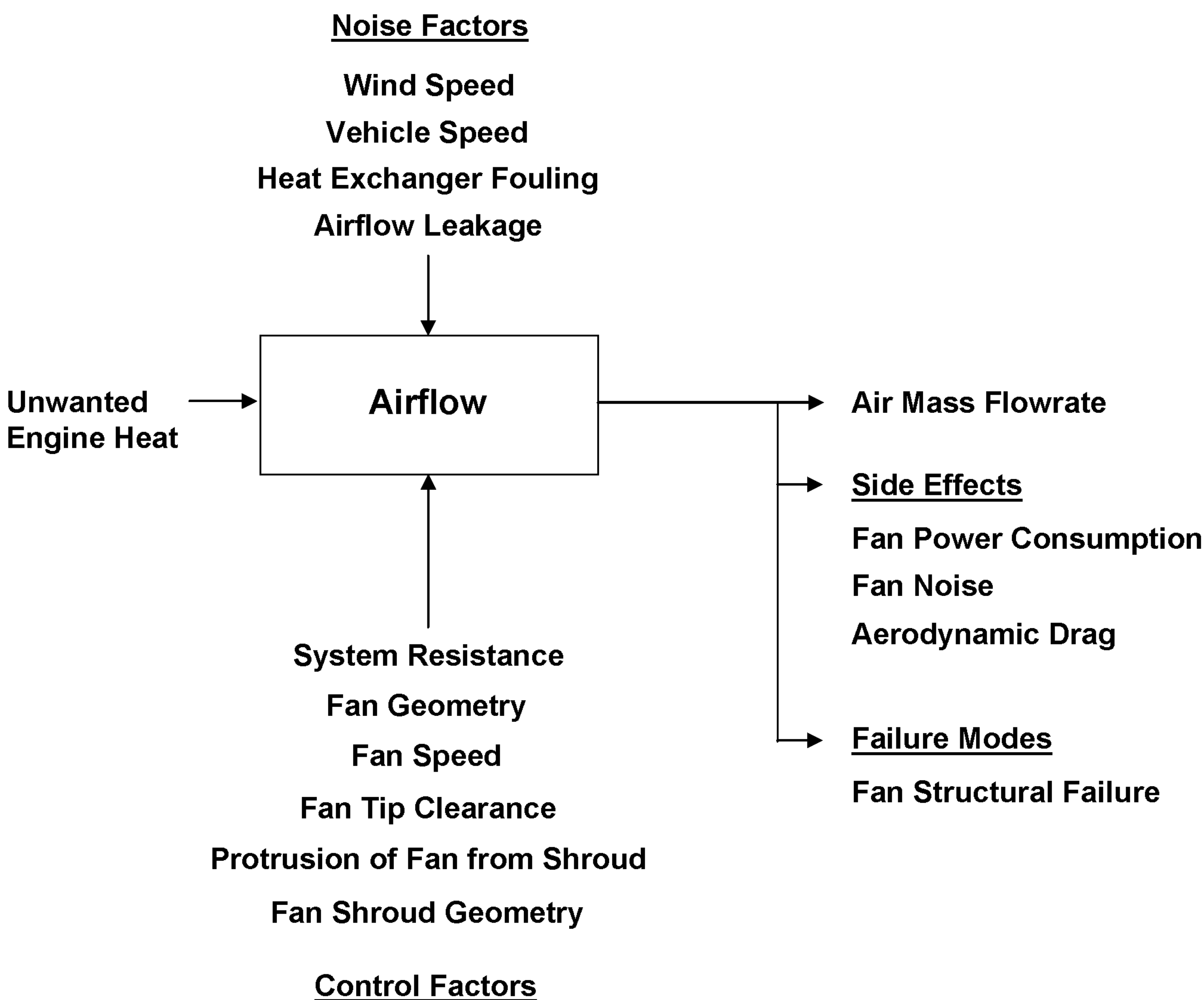
Appendix D - External Flow Subsystem



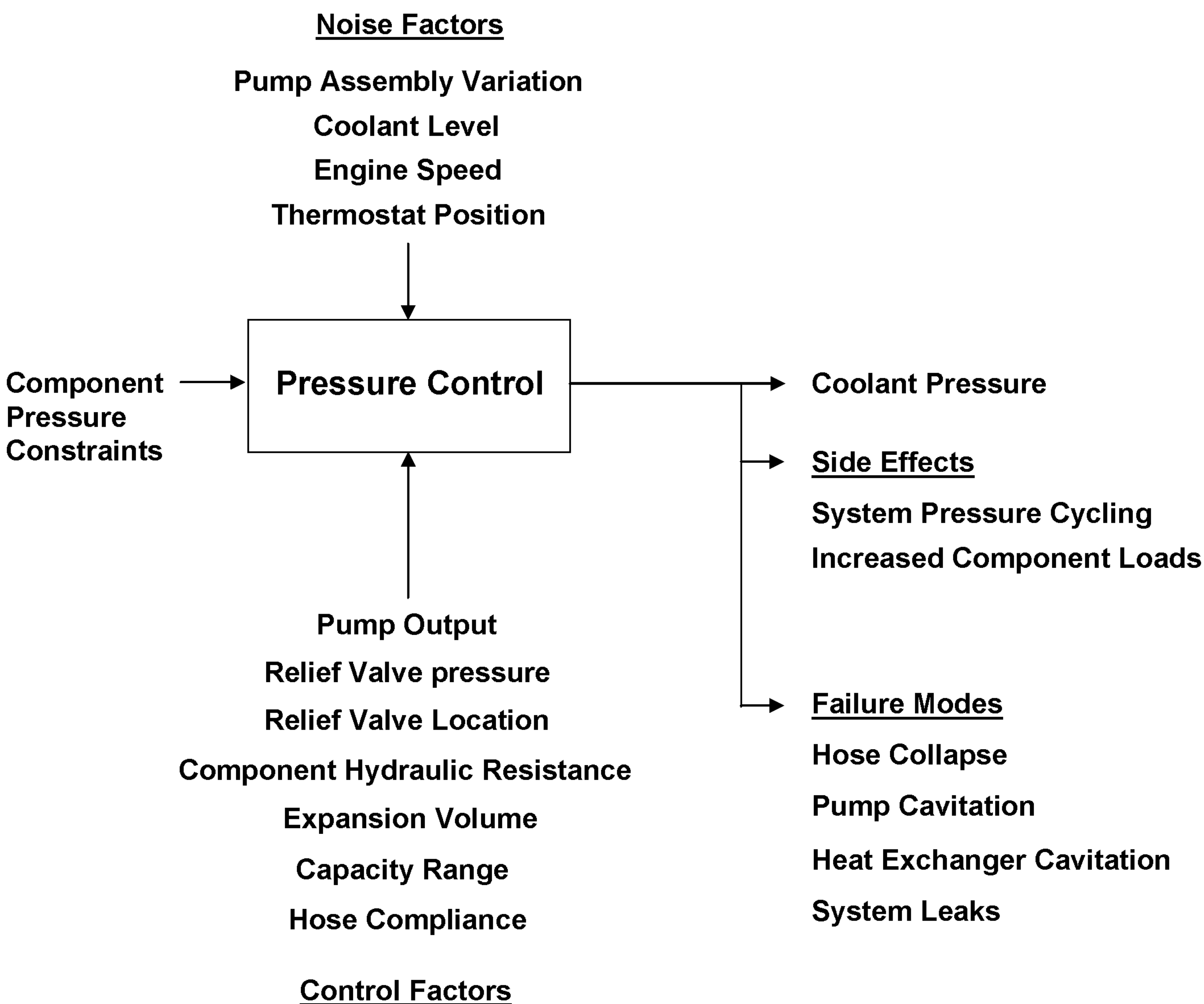
Appendix E - Heat Dissipation Subsystem



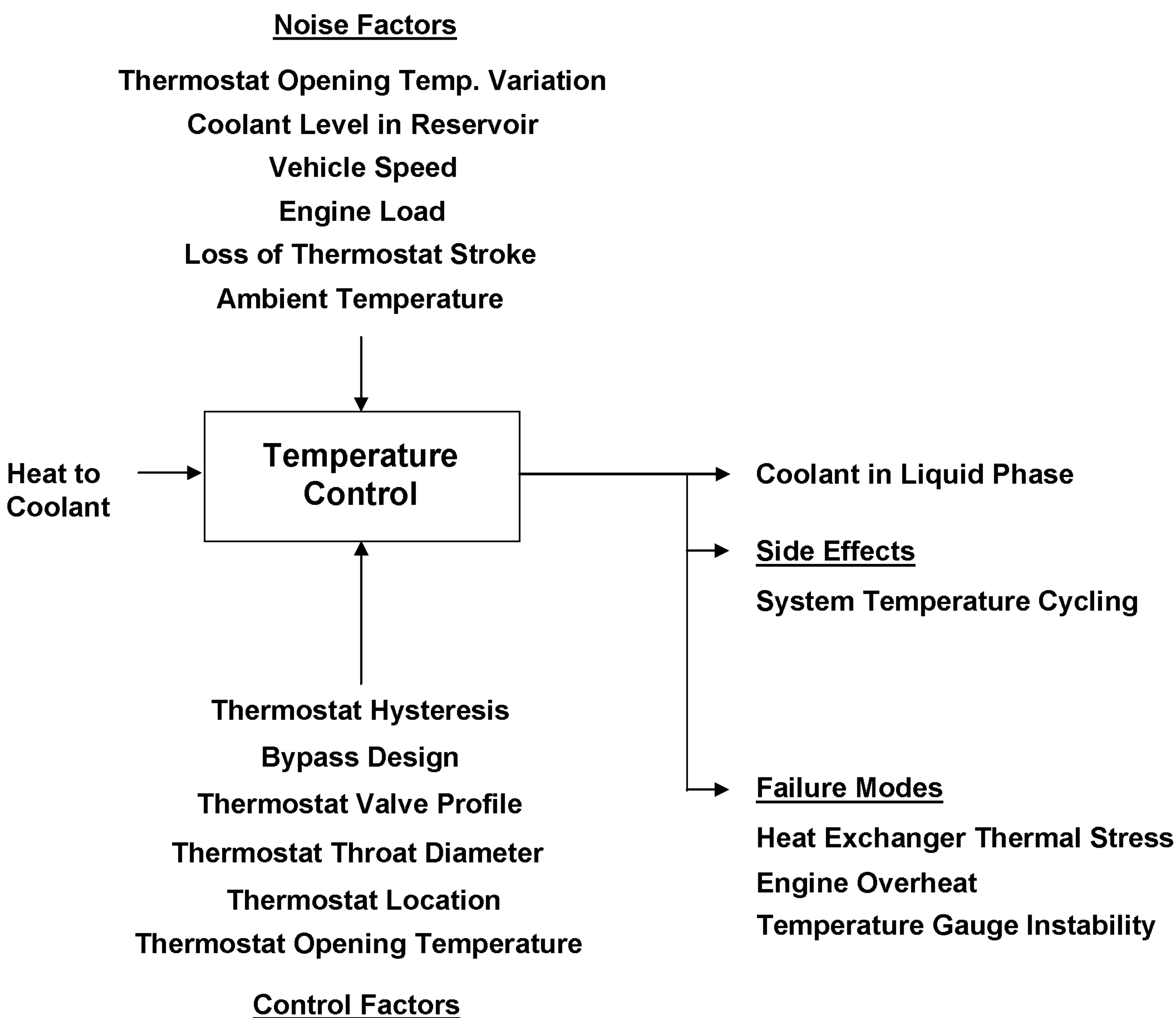
Appendix F - Airflow Subsystem



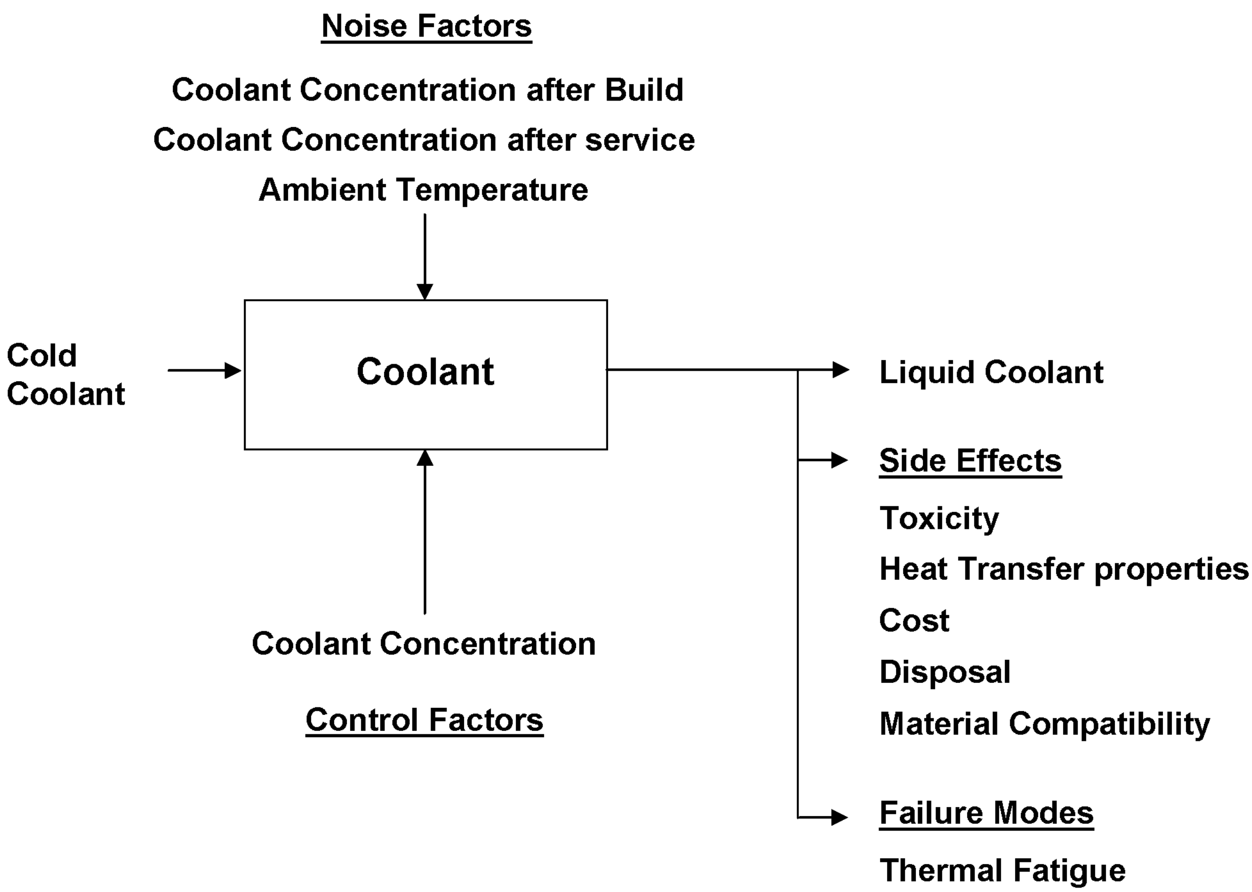
Appendix G - Pressure Control Subsystem



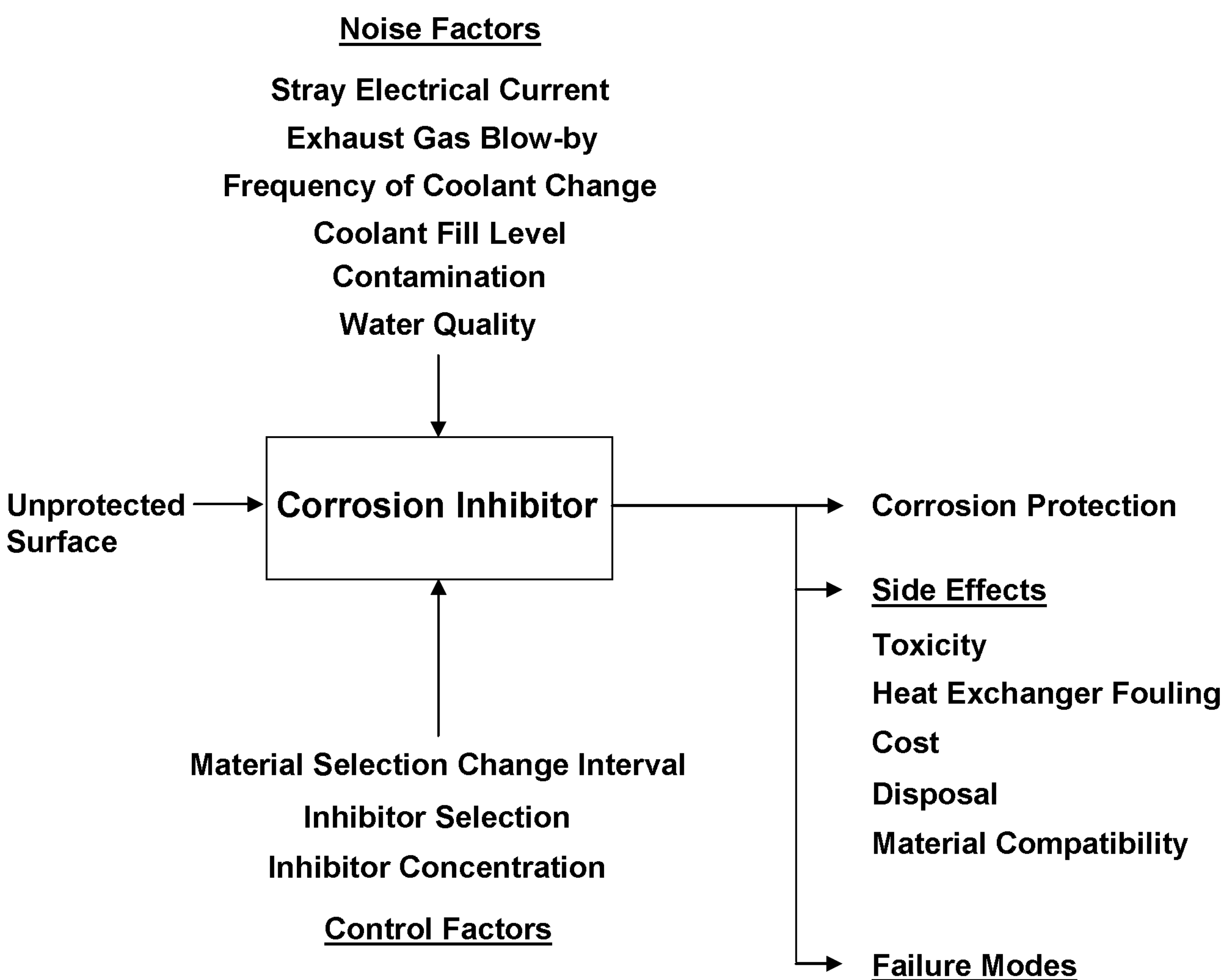
Appendix H - Temperature Control Subsystem



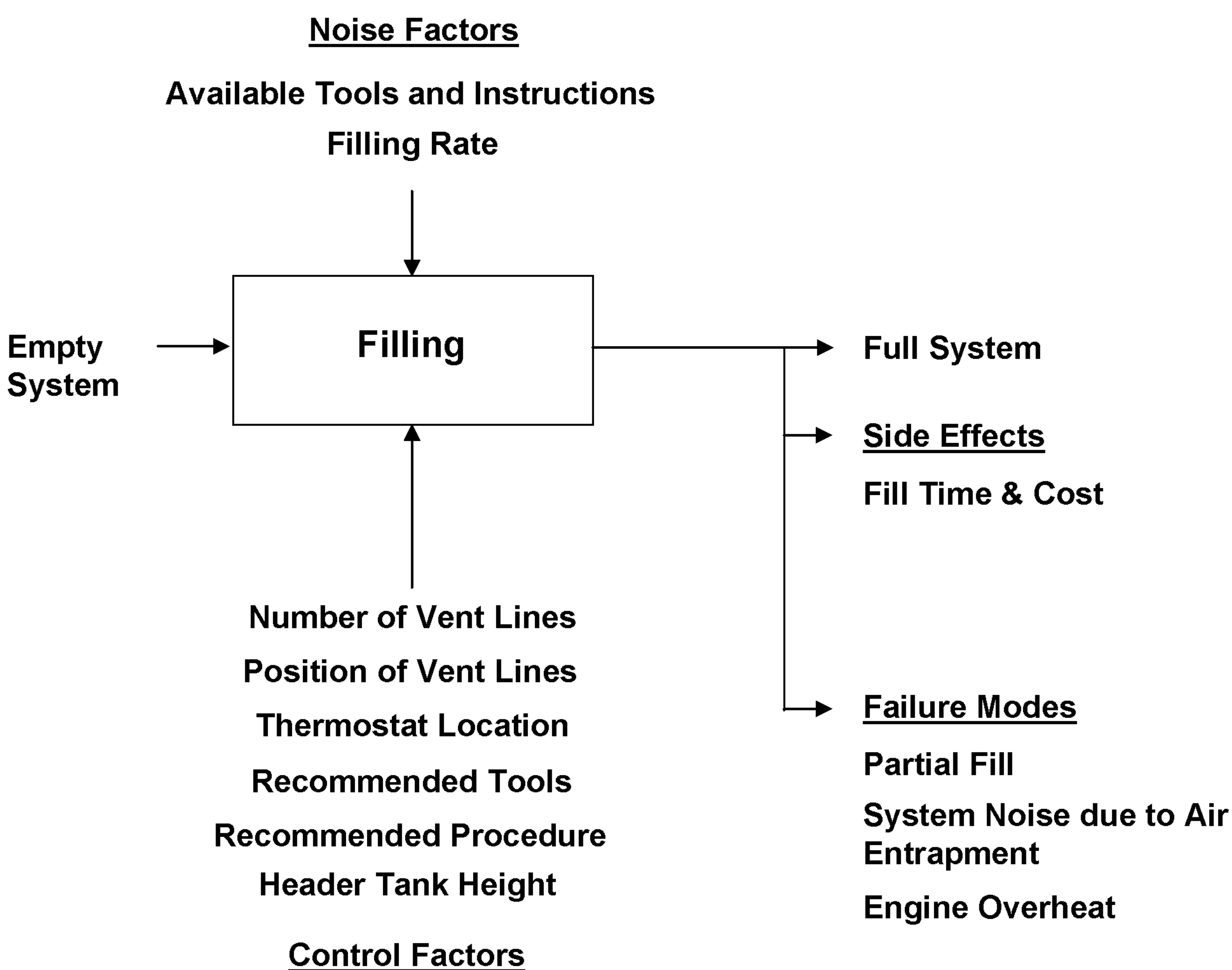
Appendix I - Coolant Subsystem



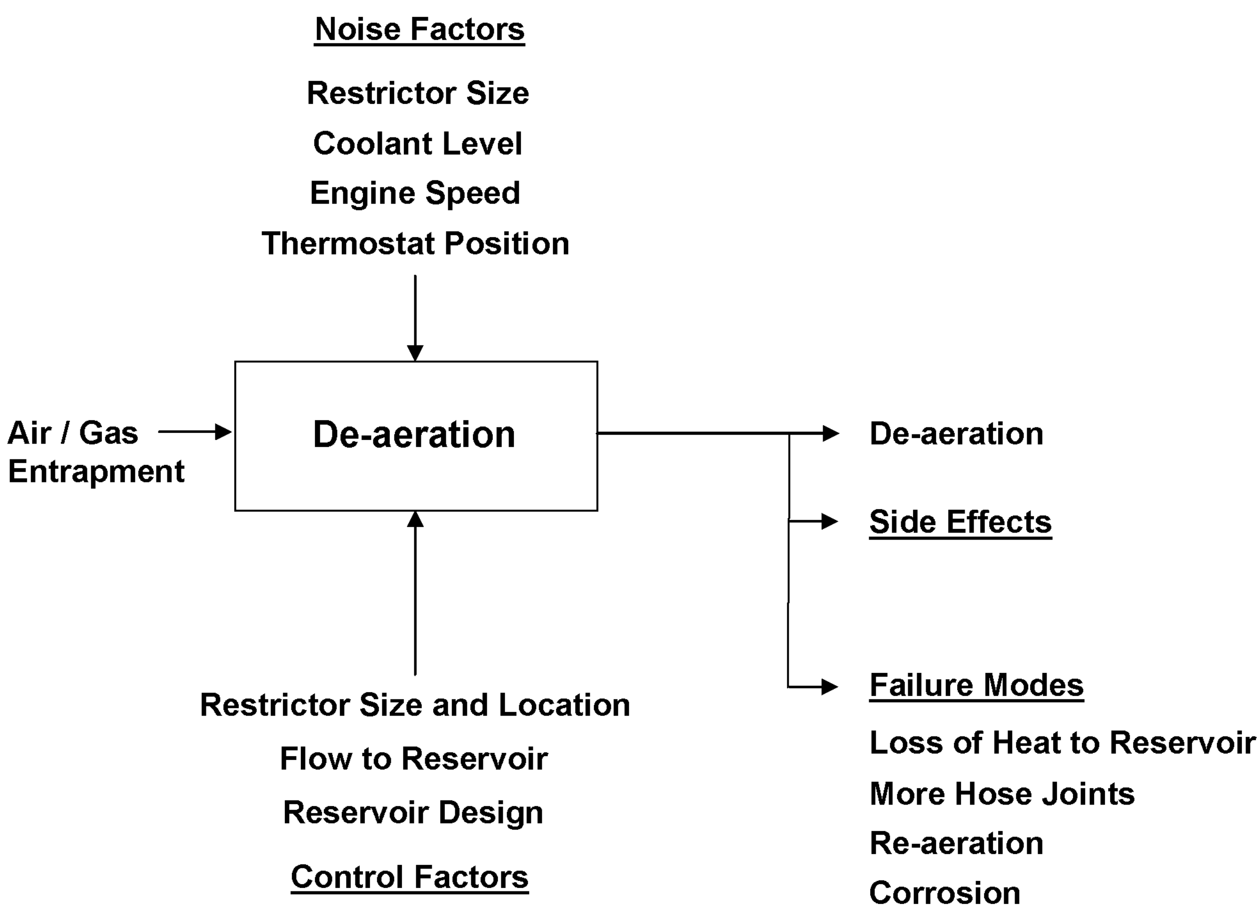
Appendix J - Coolant Subsystem



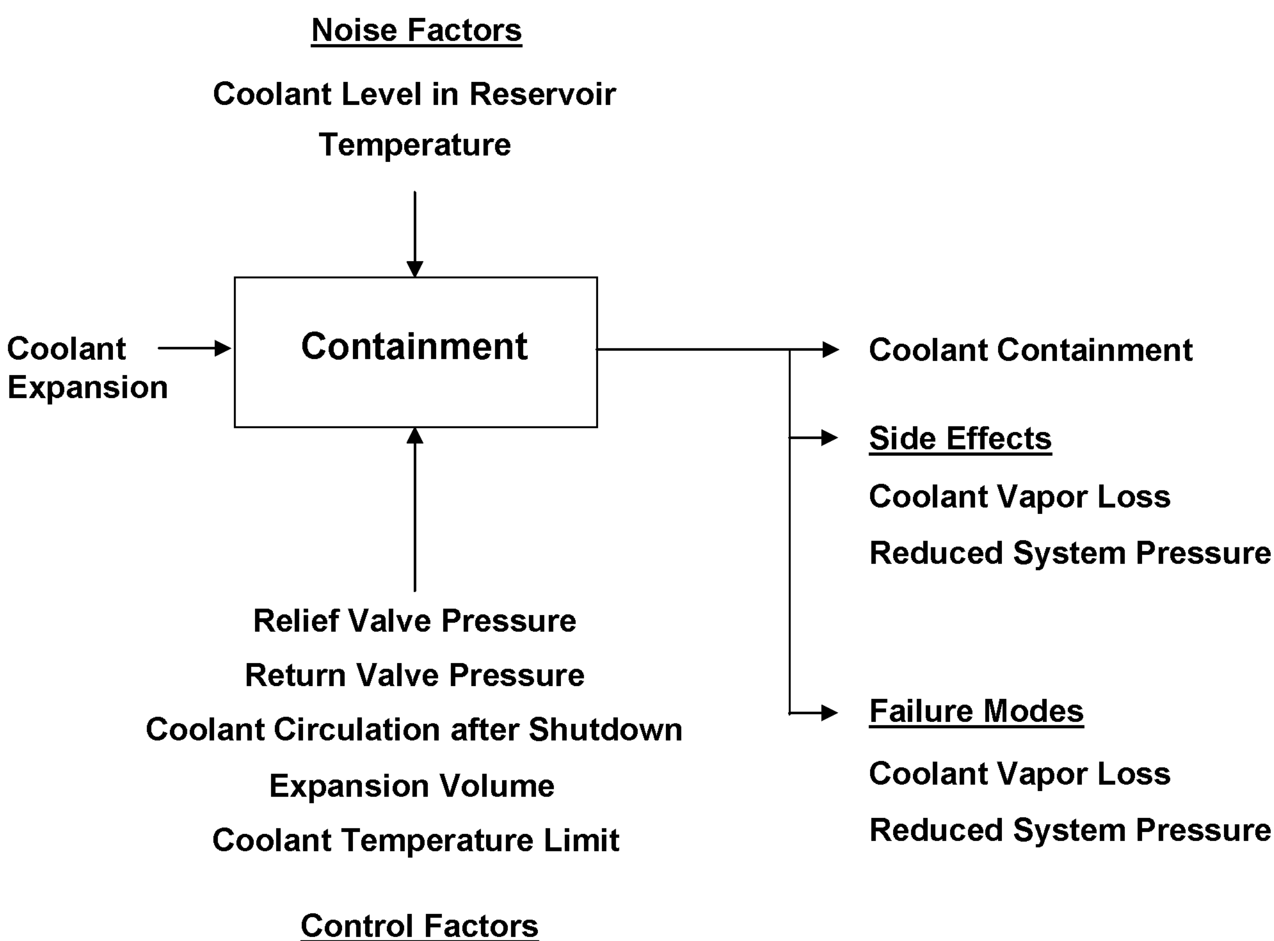
Appendix K - Filling Subsystem



Appendix L - De-aeration Subsystem



Appendix M - Containment & Sealing Subsystem



APPENDIX N - PROCEDURE FOR TESTING AND RATING OF SAE COOLING SYSTEM

1. SCOPE-- This test procedure has been set up using the following criteria; optimal response times, reduction of error, stability, ease of mounting, interfacing with remote electronics, and variable temperature and pressure ranges. Required test equipment, facilities and definitions are included.

2. DEFINITIONS

2.1 ENGINE SYSTEM -- The engine system comprises the engine block of the vehicle to be utilized and tested. The engine block is the primary source of heat generation and is dissipated by several heat transfer methods, such as through conduction and convection. The ultimate goal of the project is the efficient dissipation of the energy generated within the engine block during the combustion process through the use of a liquid based cooling system.

2.2 COOLANT -- A 50/50 mixture of commercial purity water and common antifreeze shall be used to transfer the heat generated by the engine system from the engine block through the cooling system where the heat is released via the radiator / cooling fan unit. Commercial purity water is defined as that obtained from a municipal water supply system.

2.3 DUCTING SYSTEM-- Passages that increase air flow throughout the cooling system. Any ducts that are an integral part of our design will be measured using the proper devices. Both inlet and outlet flow velocities will be measured by use of a anomometer.

2.4 DYNOMOMETER (TESTING RIG) – This device will place the proper load on the engine during testing. Various calibration techniques will be used prior to testing to ensure proper functionality.

3. EQUIPMENT

3.1 TESTING FACILITY-- Our facility will be capable of maintaining air and water temperature to a reasonable delta factor as to insure a minimum error from environmental factors.

3.2 AIR MEASUREMENT DEVICE--This device will be capable of supplying and measuring total air flow. Anemometers will be used during a test drive to develop an air flow vs. variable speed curve so that proper air flow can be used during simulation. Other application includes air flow measurement around radiator unit.

3.3 COOLANT SUPPLY-- A closed loop system tha will be capable of supplying and measuring water at a range of 150° F - 194° F and lb per minute flow. The coolant temperature for the test will be within the above mentioned range which is above the entering air temperature.

3.4 POWER EQUIPMENT SUPPLY--A source capable of providing required test voltage and current for the heater system.

4. INSTRUMENTATION

4.1 AIR TEMPERATURE

4.1.1 DISCHARGE-- Air temperature measuring instrumentation will be in a grid. Thermocouples or RTDs will be placed at the appropriate outlets to obtain an accurate average temperature. The number of thermocouples will be dependant on the ability to obtain an average temperature.

4.2 COOLANT TEMPERATURE--The temperature of the coolant entering and leaving the unit will be measured as close as possible to the engine block and radiator fan unit. Thermocouple or RTD device which will be required to read within ±0.5°F (±0.3°C) will be used.

4.3 AIR FLOW--An air pressure indicator (pitot tubes or other accepted devices) which is readable to 0.005 in H20 (1.0 Pa) will be used. Measurement of pressure may or may not be an integral part of our radiator design. It must be taken into consideration, as flow varies as a result of atmospheric pressure. As previously mentioned, air flow velocities will also be measured.

4.4 COOLANT FLOW--The quantity of coolant flowing will be measured by means of a calibrated flow meter placed in-line at a set point in our loop.

4.5 COOLANT PRESSURE--This measurement will be taken with system set at its maximum flow rate. The coolant flow rate versus pressure drop curve will be acquired by means of suitable pressure connections as close as possible to the inlet and discharge pipes by use of manometer that can be read within 0.20 in Hg (600 Pa).

4.6 ADDITIONAL INSTRUMENTATION--Additional instrumentation required for unit heater tests is a voltmeter and ampmeter to read the voltage and current at the heater motor.

5. TEST PROCEDURES
(a) Dry bulb temperature (entering the nozzle).
(b) Barometric pressure for density of test air.
(c) Discharge coolant temperature.
(d) Inlet coolant temperature.
(e) Coolant flow rate.
(f) Coolant pressure drop through heater core assembly.
(g) Inlet air temperature (average).

(h) Discharge air temperature (average).
(i) Air temperature at nozzle (average).
(j) Chamber static pressure.
(k) Static pressure drop across nozzle.
(l) Current consumption in amperes at test voltage.
(m) (OPTIONAL) Air pressure drop across unit heater

7.1 CHART AND COMPUTATIONS--CUSTOMARY UNITS

7.1.1 COOLANT

1. Flow of coolant **(Ww)** - lb/min - measured to within 2%.
2. Pressure Drop Through Unit **(ΔPw)** - in Hg - measured.
3. Temperature of Coolant Into Unit **(Tin)** - °F - measured.
4. Temperature of Coolant Out of Unit **(Tout)** - °F - measured.
5. Heat Removed From Coolant **(Qw)** - Btu/h - calculated.

EQUATION:
Qw = CpWw(Tin - Tout)(60)

Cp = Specific heat of water

7.1.2 AIR

6. Temperature of Air (Dry Bulb) - **(Tdb)** - °F - measured.
7. Corrected Barometer **(Pb)** - in Hg - measured.
8. Density of Inlet Air **(Da)** - lb/ft^3 - calculated.

EQUATION:
Da = Pb/(0.754 Ta)

Ta = 459.6 + Tdb

9. Density of Nozzle Air **(Dn)** - lb/ft^3 - calculated.

EQUATION:
Dn = Da X (Ta/Tc)

Tc = Tn + 459.6
10. Temperature of Air at Nozzle **(Tn)** - °F - measured.
11. Static Pressure Drop Across Nozzle **(ΔPn)** - in H2O - measured.
12. Actual Air Flow **(Vact)** – cfm - measured by means of calibrated nozzle.
13. Actual Air Flow **(Wa)** - lb/h - calculated.

EQUATION:
Wa = VactDn(60)

14. Air Flow Corrected to Standard Air Conditions **(Vstd)** – cfm - calculated.

EQUATION:
Vstd = Vact (Dn/0.075)

15. Average Temperature of Air Into Unit **(Tin)** - °F - measured.
16. Average Temperature of Air Out of Unit **(Tout)** - °F - measured.
17. Actual Heat Gained by Air **(Qact)** - Btu/h - calculated.

EQUATION:
Qact = WaCp(Tout - Tin)

Cp = specific heat of air

NOTE: If the optional insulated plenum and thermocouple location are used, then the heat loss through the insulated plenum must be accounted for in the heat gained by the air calculations.

18. **Heat Dissipation** - Btu/h/150°FΔT - calculated.

EQUATION:
Heat Dissipation = (Qact X 150)/ΔT

ΔT = Temperature difference between inlet air and inlet water - °F. (Item 3 minus Item 15.)

19. (OPTIONAL) Pressure Drop Across Unit (ΔPa) - in H_2O - measured.

7.1.3 FAN

20. Fan – **volts** - measured.
21. Fan – **amps** - measured.
22. Fan speed – **rpm** - measured.

Appendix O – Sensors and Equipment

Pressure

- Coolant pressure in (manometer)
- Coolant pressure out (manometer)
- Ambient pressure (nominal)
- Pressure into pump (manometer)
- Pressure out of pump (manometer)
- Pressure drop across block (2 manometers)
- Pressure from engine to swirlpot (manometer)
- Pressure out of swirl (manometer)

Temperature

- Heater temp (thermometer or heater setting which is nominal)
- Fan air temp or intake air (thermometer)
- Coolant temp in (we may be able to find a flow meter capable of measuring temp, if not we can use a thermocouple)
- Coolant temp out (we may be able to find a flow meter capable of measuring temp, if not we can use a thermocouple)
- Radiator surface temperature
  * may need grid of sensors in core (figure out number of sensors)
- Ambient temp (thermometer)
- Ave temp across block at top of cylinder heads (4 thermocouples)
- Oil temp in block (thermocouple)
- Oil temp out of block (thermocouple)

Flow

- Air flow from fan (anemometer)
- Air flow across radiator (anemometer)
- Coolant flow meter in and out of radiator (flow meter)
- Air flow across vehicle at variable speed so that we can use proper fan speed in simulation (approx. 4 anemometers)

Voltage

- Fan voltage / amp / rpm (multimeter)
- System voltage (nominal)

Data Acquisition

- Laptop
- Plotter
- Software
- Leads (approximately 6 ft x # of sensors)
- Bread board (with # of channels equal to the # of sensors)

Additional Equipment

- Heater (Range between 32 ^{0}F – 110 ^{0}F) ?
- Fan (capable of variable speed)

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