Federal Aviation Administration

Low Temperature Flowability Test Plan

PAFI-RTP-001

PAFI Rig #1 Cold Flow Test

Revision A

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PREFACE

This test plan specifies the requirements for conducting comparative materials compatibility screening tests under the FAA's piston aviation fuels initiative (PAFI). This document is derived from extensive FAA and industry experience and best practices for evaluating the suitability of aviation fuels for use in the piston powered general aviation fleet. This document is used by the FAA to compare and evaluate new aviation fuels relative to the performance of 100LL aviation gasoline that meets ASTM D910.

In addition to the candidate unleaded fuel, an ASTM D910 fuel formulation is required for the screening tests under this plan.

This document is not intended to provide a method to obtain data to serve as a showing of compliance to regulatory requirements for the certification of aircraft or aircraft engines.

Furthermore, the material in this document does not change or permit deviations from existing regulatory requirements. This material is neither mandatory nor regulatory in nature. Use of this document or any derivative, in an attempt to obtain an FAA authorization of an alternative aviation fuel, should be pre-coordinated and approved by the appropriate FAA office(s) as part of an approved qualification program.

Successful completion of this test plan provides data that may support both FAA Fleet authorization and development of an ASTM production specification for PAFI Fuels. It also allows the collection of data to be used to generate performance and detonation performance values in support of other candidate fuel types being investigated under various FAA Research & Development projects.

References made to the Alternative Fuels Program Office or AFPO, refer to the group within the FAA that is responsible for the PAFI program. At the time of this revision, that group is the AIR-650 organization. Please see https://www.faa.gov/about/initiatives/avgas/org_info.

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Rig Test Plan
PAFI-RTP-001
Low Temperature Flowability Test

1. SCOPE

This test plan specifies the requirements and procedures for conducting comparative cold flow operability testing of an unleaded fuel to generate data required for participating in the FAA Piston Aviation Fuels Initiative (PAFI) test program.

This data will be used for the evaluation of an unleaded fuel being tested in the PAFI test program.

Specific objectives of this comparative plan are defined as follows:

1) Determine the acceptable performance of aircraft hardware when flowed with an unleaded test fuel as compared to the performance when flowed with an ASTM D910 compliant 100LL aviation gasoline.

   Specific performances to be evaluated include; deviation in flows or pressure across defined aircraft hardware, failure to actuate, plugging or other observed operation deviations.

The test plan includes the requirements for confirming baseline condition, test set-up, instrumentation, specimen collection, and supporting documentation such as fuel certification documents as prerequisites to the testing identified.

Comparative low temperature flowability tests between 100LL aviation gasoline (AvGas) and an unleaded test fuel are specified for hardware at cold soaked fuel temperatures of -20, -40, and -58 °C (-4, -40, -72 °F). During the testing, the hardware temperature may fluctuate with operations but the fuel shall remain cooled to the target temperature for the duration of the test.

Specified aircraft hardware is representative of six typical aircraft design philosophies, representing:

1) An RSA fuel injection system,
2) A Continental fuel injection system,
3) A Textron airframe system,
4) A Light General Aviation (GA) airframe system,
5) A Rotorcraft (helicopter) airframe system, and
6) A Cirrus airframe system

Each test is performed by providing operation inputs of fuel flow and pressures representative of those experienced during a full flight profile. These six systems are designated as loops for convenience.

Comparative cold flow testing consists of documenting the observed fuel flows, pressures, and fuel pump speed, voltage, and amperage across representative hardware as the system is exercised over three- to four-hour flight profiles. Data collected includes fuel pressure and fuel flows at designated locations, and the speed, voltage, and amperage of fuel pumps, at specified time intervals. Monitoring of the fuel temperatures at the fuel tank will be performed for temperature control. Fuel samples are to be collected and tested for water content by Karl Fischer per ASTM D6304 at specified temperatures, and base fuel surface tension at 25 °C, density, and viscosity at 0 and 25 °C and will be reported. One way to measure the surface tension is per ASTM D1331, Method A. The kinematic viscosity may be measured by any ASTM standard including but not limited to; D445 Kinematic Viscosity, D7945 Derived Kinematic Viscosity, or D8092 Kinematic Viscosity Using a Microchannel Viscometer. The method used for determining surface tension and viscosity shall be reported.

Requirements for confirming hardware configuration, component health, test equipment, test instrumentation, and supporting documentation such as component and fuel certification are prerequisites to the testing identified.

1.1. PROVISOS

The following identifies significant assumptions, requirements, and provisions associated with the testing prescribed within this test plan. Testing performed pursuant to this test plan provides data supporting 1) FAA fleet authorization for PAFI unleaded fuels, and 2) the development of an ASTM International aviation gasoline production specification.

All the results of the testing performed and the associated data collected under the following test plan are considered competition sensitive and proprietary by the fuel offeror and are subject to NDA between the FAA and the Fuel Offeror.

Unlike a typical engine test and certification project, this test is using the engine and aircraft accessories as the test equipment; the fuel becomes the test article. It is specified that the same physical rigs are used for both the D910 compliant 100LL AvGas and the unleaded test fuel. All components shall be purchased new and shall have all necessary accompanying FAA compliant paperwork as part of the certification documentation.

NOTE: In the event testing is conducted outside the FAA's William J. Hughes Technical Center, testing performed to this test plan may be witnessed by an identified designated representative of the FAA. This may be achieved through the use of a Designated Engineering Representative (DER), or other representative approved by the AFPO or PAFI Advisory Committee prior to executing testing.

2. OBJECTIVES

The objectives of the PAFI comparative cold flowability tests are defined as follows.

1) *Validate rig performance with respect to fuel flows and pressures using ASTM D910 compliant aviation gasoline at room temperature.*
2) *Flow each of the six individual loops on the baseline D910 100LL aviation gasoline at each of the three test temperatures per the provided test protocol. Repeat the flow testing on each loop using the unleaded test fuel at each of the three temperatures.*
3) *Measure and record the fuel pressure and flow, and any changes across the components at designated locations throughout the test cycles for each of the three temperature runs, on the baseline and proposed test fuel(s).*
4) *Collect and measure the moisture content of the fuel prior to the test start and after each of the three temperature runs, on all fuels. For each fuel report the viscosity at a minimum of three temperatures, the density, and the surface tension.*
5) *Document and compare changes in fuel flows and pressures across components.*

3. BACKGROUND

Historically aviation gasoline has displayed a resistance to freezing and an observable stability when cold soaked to temperatures as low as -58 °C (-72 °F). This is primarily due to the chemical composition of the fuel when produced in compliance with ASTM D910, a result of the original military requirements for the fuel to have a freezing point no higher than -60 °C (-76 °F). High altitude and arctic conditions can still cold soak aircraft and ground fuel storage to these extreme low temperatures.

In order to blend fuels with the necessary detonation resistance without using lead (Pb), blending materials having different physical properties with respect to temperature could potentially result in different operational performance when flowed through aircraft hardware. Therefore, it is desirable to confirm the performance of hardware in the engine and airframe fuel systems at the lowest operating temperatures. This data is used in concert with the cold storage information developed in RTP-005 Freezer Testing to evaluate comparative cold temperature performance of the test fuel.

Because the chemical composition of the alternative chemicals used to blend unleaded fuels may have different water saturation properties, different viscosity profiles, or different density profiles, it is desirous to confirm the performance of

the aircraft hardware at low temperatures. Impacts of concern include changes in fuel flows, changes in fuel operating pressures, changes in pressure drops across filters and valves, and degradation of the hardware components' ability to operate. These behaviors are the operational counterparts to viscosity, surface tension, freeze point and density. Additionally, it is necessary to confirm that fuel blend components do not separate at low temperatures.

During the original FAA PAFI test development, a full design activity was undertaken to identify the representative components to be tested. The test developers began with aircraft likely to require greater octane fuel, represented by larger aircraft with high compression, large displacement engines, and continued through a design spiral to balance the desired aircraft/engine combinations, component availability, and critical data collection requirements. This resulted in the development of six representative rigs, referred to as 'loops' and identified for convenience by the representative manufacturer of each design philosophy.

The FAA's "ideal" for a fuel component loop representing general aviation airframes was to mimic an aircraft such as the Piper Navajo or the Cessna 421 aircraft series. Ultimately, the procurement of new components for these aircraft was deemed problematic.

While developing the cold flow evaluation program, one of the challenges identified as critical to the testing was access to new aircraft components. The use of remanufactured or overhauled components was initially considered in order to improve component availability. The use of remanufactured or overhauled hardware was rejected based on concerns regarding potential variability in condition between like part numbers. Furthermore, the existing supply chain requirement for submitting used parts (cores) in order to purchase new parts further prevented access to these remanufactured and overhauled components. The difficulties in procuring sufficient components resulted in both the presented test loops, as well as the test protocol which runs both the baseline 100LL and the unleaded test fuel in the same hardware. The six loops developed during PAFI Phase 1 were:

1) RSA Loop
    a. Components representative of the Lycoming RSA fuel injection system
2) Continental Loop
    a. Components representative of the Continental Motors fuel injection system
3) Textron Loop
    a. Components representative of the Textron airframe fuel system, single engine
4) Piper/Light GA Loop
    a. Components representative of the Piper and other similar single engine, light general aviation airframe fuel systems
5) Enstrom Loop

   a. Components representative of the Enstrom and other piston powered rotorcraft airframe fuel systems
6) A Cirrus airframe system
   a. Components representative of the Cirrus airframe fuel systems

4. PAFI RIG SCREENING TEST PLANS

The matrix of rig screening test plans supporting the test protocols identified in TAC-PRJ-008 latest revision is presented as follows. The test plans follow a common format with general procedures, processes, and test instrumentation being common to all. The current plan is highlighted in the list below:

RIG SCREENING TEST PLANS

PAFI-RTP-001, Cold Flow Hardware Test
PAFI-RTP-002, Carburetor Icing Test (Incorporated into Engine Test Plan(s))
PAFI-RTP-003, Dynamic/Operational Hardware Test (Removed)
PAFI-RTP-004, Long Term Storage Test, Ambient and Elevated
PAFI-RTP-005, Cold Storage Stability Test
PAFI-RTP-006, Hot Surface Ignition Temperature Test, (Removed)
PAFI-RTP-007, Full Scale Engine Emissions Test (Not Released)
PAFI-RTP-008, Comingling Evaluation with 100LL (Not Released)
PAFI-RTP-009, Dynamic Diaphragm Test
PAFI-RTP-010, Fuel Sump Valve Test
PAFI-RTP-011, Vented Drum Storage Test

Test plans prepared in support of the FAA PAFI test program for unleaded fuels are subject to the following review and approval protocol.

1) PAFI rig test plans follow a format and content consistent with established practice for FAA compliance projects.
2) Draft test plans are furnished to the FAA AFPO office for review and approval prior to release to the TAC.
3) Upon concurrence from AFPO, the test plan is to be formally furnished to the PAFI TAC for review and concurrence preceded by FAA Contracts review and authorization for release to the TAC.
4) A final test plan is to then be released, incorporating changes resulting from the TAC review.
5) All changes and referrals to this test plan should reference the latest revision level and date.

5. APPLICABLE FAA & ASTM REQUIREMENTS

The following is a listing of the applicable FAA and ASTM documents which contain information relevant to the testing specified by this test plan.

5.1. FAA REGULATIONS

1) FAA Advisory Circular 33.19-1, "Guidance Material for 14 CFR §33.19 Durability for Reciprocating Engine Redesigned Parts"
2) FAA Advisory Circular AC33.4-1, "Instructions for Continued Airworthiness"
3) FAA Order 8110.4C, "Type Certification Process"

5.2. SAE STANDARDS

There are no SAE standards applicable to the testing.

5.3. ASTM GUIDANCE & PRACTICES

ASTM guidance and standards applicable to the testing identified are listed as follows. Data provided by this test plan will support development of an ASTM production specification for the unleaded fuel.

1) ASTM D6304 "Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration"

2) ASTM D7826-19a "Standard Guide for Evaluation of New Aviation Gasolines and New Aviation Gasoline Additives"

6. APPLICABLE OEM DOCUMENTS

No applicable OEM documents.

7. DESCRIPTION OF TEST ARTICLES

All of the following aircraft parts shall be purchased new with all appropriate FAA Form 8130-3 Airworthiness Approval tags. To facilitate procurement, each loop is presented below as its own subsection. None of the loops utilize an "in tank" boost pump per the FAA's instruction.

Note: there are components with long lead-times and delivery schedules of potentially multiple months. Purchase of **new** parts, as is required for this testing, is typically achieved through the use of distributors. The ability to purchase parts from some industrial facilities requires an industrial account not typically available

to individuals. Private access to parts through aftermarket distributors supplying parts for amateur built aircraft typically do not provide components with an FAA form 8130-3 tag. Components not having an 8130-3 tag, even where a vendor has described the part as new, are not permitted for this test. Overhauled or remanufactured parts are **not** acceptable.

The following list of recommended parts is comprised of hardware specifically identified and used during the original FAA PAFI testing. Any deviations from the following component list must be approved by the FAA AFPO representative prior to testing. Actual sourcing is at the discretion of the testing organization.

Note: Given the logistics of parts procurement and the scheduling of the cryogenic test chamber, it is prudent to procure multiples of components such as check valves and pumps. If an issue arises during testing, such as a leak, crack, part failure through no fault of the fuel, or other operational issue, parts may need to be swapped quickly to provide continuity of the testing. In the event of a component change, enter a notation in the test logs regarding which part was swapped, when and why, and record this information in the final report. If the failure occurs during a test cycle, the part is replaced and the entire cycle (idle, 80%, and max flows) must be repeated, from the start, for that fuel candidate on that loop. In most cases, if fuel resources permit, the matching 100LL baseline fuel test cycle should also be repeated to remove any question of cause of changes in performance after part replacement.

7.1. FLOW MONITORING (ALL LOOPS)

Determination of the target “power”; idle, 80%, 100%, is determined by fuel flow, W_f. Fuel flow within the rig is measured by the flow meter and monitored by the matching flow display. The flowmeter given in 7.1.1 is a test component where an aircraft fuel flowmeter is to be operated in the candidate fuel at the target temperatures. This flowmeter may be used as the primary flow measuring device, or a separate industrial or other redundant flow meter may be added to the loop if greater accuracy or reliability is desired. Fuel flow is a critical component of this test so redundancy of fuel flow measurement is encouraged.

7.1.1. FLOWMETER

A turbine flowmeter that is representative of a flowmeter used on the aircraft to monitor fuel flow to the engine is required. The purpose of this flowmeter is to monitor the fuel flow and is not a part of the compatibility evaluation.

The specified flowmeter is the FLoScan 201A-6. The FLoScan 201A-6 flowmeter used during the original PAFI testing has the following performance properties with gasoline.

- Flow range 0.3 to 30 gph
- K factor (pulses/gallon @ 16 gph) -32,000
- Pressure drop 0.6 psi @ 15 gph

	2.4 psi @ 30 gph
• Working pressure	200 psi
• Temperature range	-65/100 °C
• Bearing life expectancy	10,000 hrs
• Electrical Specifications	12-15 VDC between + and – wires 30 – 50 mA @ 12 VDC

This flow meter has since been superseded by an improved model, and specific FAA approval for the most recent type of turbine flowmeter may need to be obtained as part of the test plan approval. A matching flow display is also required.

7.1.2. FLOW DISPLAY

The flow display used during the original testing was matched to the turbine flow meter FLoScan 201A-6 referenced in Section 7.1.1. A flow display matched to the selected turbine flowmeter is required and should be approved by the FAA with the flowmeter.

7.2. RSA LOOP

The RSA loop includes the components used in an RSA fuel injection system.

7.2.1. DIAPHRAGM FUEL PUMP

Lycoming P/N 62B26931

7.2.2. IDLER GEAR WITH PUMP CAM

Lycoming P/N SL75072

Note that this component requires the **entire** idler gear assembly **including** pump cam, not just the idler gear.

7.2.3. RSA INJECTION SERVO

Precision Airmotive P/N 2549038-4-F (Note: the “F” indicates new unit)

7.2.4. RSA FLOW DIVIDER

Precision Airmotive P/N 2524232-2-F

7.2.5. AIR BLEED FUEL NOZZLE

Precision Airmotive P/N 2524846-2

7.3. CONTINENTAL LOOP

The Continental loop includes the components used in representative Continental Motors fuel injection systems.

7.3.1. High Pressure Fuel Pump Assembly

Continental P/N 649368-60A4

7.3.2. Throttle Body

Continental P/N 656785-1

7.3.3. Manifold and Injectors (Flow Divider)

Continental P/N 646433-12A4

7.4. Textron Loop

The Textron loop includes the components used in representative Textron airframe fuel systems.

7.4.1. Electronic Fuel Pump

Cessna P/N 5100-00-4

7.4.2. Fuel Selector Valve

Cessna P/N 9851096-5

7.5. Piper/Light GA Loop

The Piper / Light GA loop includes components used in representative Piper aircraft as well as high-use general aviation interrupter style pumps.

7.5.1. Interrupter Fuel Pump with Integral Filer and Check Valve

PMA Products Inc. P/N CA 35328-800

7.5.2. Fuel Check Valve

The Andair Check valve specified is produced in the United Kingdom and is a complete closure check valve. This valve does not have a bleed hole. The cracking pressure is between 0.4 and 0.7 P.S.I.

Andair P/N CK375

7.5.3. Fuel Check Valve (#2)

Beechcraft P/N 50-380170-11 (Used on the King Air)

7.5.4. Shut Off / Selector Valve

Allan P/N 6S122

Piper P/N 491-947

7.5.5. PRESSURE SWITCH

Piper P/N 688-192

7.6. ENSTROM LOOP

The Enstrom loop includes components representative of the components used on piston powered rotorcraft.

7.6.1. SHUT OFF / SELECTOR VALVE

Enstrom P/N 280-12400-1

7.6.2. BOOST PUMP

Weldon P/N A10019-E; 28 Volt Fuel Pump

7.6.3. FUEL STRAINER

SigmaTek P/N G199-105-4; 40 µm particle size with bypass valve and 30 P.S.I. pressure test

7.7. CIRRUS LOOP

The Cirrus loop includes the components used in representative Cirrus airframe fuel systems. Cirrus parts are only available from Cirrus.

7.7.1. FUEL SELECTOR VALVE

Cirrus P/N FS2520 – D204B

7.7.2. FUEL PUMP

Dukes P/N 5217-00-3

7.7.3. FUEL STRAINER

Cirrus P/N 14069-002

7.7.4. FLOWMETER

Cirrus uses an integral fuel flowmeter. This flowmeter is tested as a component but for commonality in the RTP-001 test data, this flowmeter is not used to monitor the loop fuel flow.

Cirrus P/N 15415-002

7.7.5. CHECK VALVE

8. DUKES P/N 366-00DEFINITIONS & TERMINOLOGY

Definitions, terminology and abbreviations specific to this document and to FAA nomenclature are summarized in the following section.

8.1. CALIBRATION

Calibration is a set of actions that establishes that the instrument which is being calibrated is equal to or reports values equal to a standard. The unknown, the instrument being calibrated, will be checked against a known, the standard, at several different points, and adjustments made to the unknown to bring it into alignment with the standard.

8.2. SAMPLE

Within this document the following concept is meant by the term “sample.” A sample is the specific material to be prepared as specimens and exposed to test fluids. For example, 100LL AvGas is a sample, and UL100 test fuel is a second sample.

8.3. SAMPLE SET

A sample set is all of the individual specimens and all of the test fluids comprising a set of samples to generate a set of data. For example, the pretest and posttest specimens from the 100LL and the pretest and posttest specimens from the UL100 experimental test fuel at -40 °F comprise the “-40 °F Sample Set.”

8.4. SPECIMEN

Within this document the following concept is meant by the term “specimen”. Specimens are the individual pieces/aliquots collected from the sample materials. For example, the two individual fuel volumes collected from the test sample (the fuel) are the test specimens for a single temperature test of the test fuel.

8.5. VALIDATION

As opposed to calibration, validation is the act of documenting that an instrument will actually and consistently give expected results. This may be done by measuring a specimen with a known value and confirming the instrument reports that value within the repeatability of the instrument. If the expected value does not result, validation has failed and some additional action must be taken to repair or adjust (calibrate) the instrument.

9. CONFORMITY

9.1. HARDWARE

Confirmation that the hardware component test articles configuration complies with the respective design data, bill of materials, and associated specifications is a fundamental requirement. Hardware shall be established as prescribed in the following sections on the basis of certificates of compliance and certificates of analysis.

Verification of test article conformance with specification shall be established through the reliance on FAA Form 8130-3, Certificates of Conformance (CoC), and/or Certificates of Analysis (CoA) which document that the hardware meets the intent of 14 CFR Part 21.33 Inspections and Tests, which states the following:

> *"(b) Each applicant must make all inspections and tests necessary to determine--*
> *(1) Compliance with the applicable airworthiness, aircraft noise, fuel venting, and exhaust emission requirements;*
> *(2) That materials and products conform to the specifications in the type design;*
> *(3) That parts of the products conform to the drawings in the type design; and*
> *(4) That the manufacturing processes, construction and assembly conform to those specified in the type design"*

The PAFI procedure for documenting the test hardware conform to specification is NOT a traditional FAA conformity process, but rather is a process that meets the intent "That materials and products conform to the specifications...." through the use of CoC and CoA documentation.

9.2. TEST FUELS

Each PAFI test fuel shall be shown to conform to the complete specification approved by the AFPO, as documented by a CoA furnished with each fuel batch or bulk volume delivered by the fuel supplier to the test facility. In addition, representative data must be generated by an independent 3rd party laboratory for specific pre- and post-test criteria. Pre-test samples should be from fuel collected from the original shipping containers 'as received' by the Test Facility. Analysis must be performed on the fuel samples in accordance with Appendix A. Deviations from the fuel specification shall require approval of AFPO. The full Test Fuel CoA as well as the pre and post-test analysis specified in Appendix A must be included in the test results report.

NOTE: A five-gallon retained sample of the test fuel 'as received' at the test facility must be collected and stored until completion of the PAFI test program. See PAFI-FHP-001.

NOTE: The impact of differences in a fuel's propensity to draw water (its hydrophilic nature) and the potential for this water to freeze in the carburetor, is considered during Carburetor Icing testing and PAFI-RTP-005 Cold Storage testing.

9.3. SAMPLES

Each sample material shall be shown to conform to its respective specification or qualification as documented by a certificate of quality, certificate of conformance, FAA form 8130, or other provided documentation. Samples comprised of multiple pieces, sheets, or other units shall be purchased from single lots. Where practical, samples shall be purchased in single units, i.e., a single length of hose, for preparation into specimens. Lot information, certificates of quality, certificates of conformances, or other identifying documentation shall be included in the test results reports.

10. SAFETY PROCEDURES

This document does not purport to address all safety considerations. This document does not replace or supersede individual instrument documentation, Federal, State, and local regulations, site procedures, or general industry practices. Appropriate safety precautions are the responsibility of the Test Facility conducting the test. The Test Facility shall establish and ensure compliance with all applicable safety and health standards. Prior to initiation of test, each test set-up shall be inspected for safe practices. Consideration for personal protective gear (PPE) is the responsibility of the Test Facility.

10.1. STATIC CHARGE

10.1.1. GROUNDING (D4057, SECTION 5.4.1)

Fires and explosions have occurred as a result of hydrocarbon vapors being ignited by static electricity. If electrical charges are not grounded, they are unable to dissipate and become “static.” This static electric charge can accumulate and freely migrate to a single point on the sample container by a difference in electrical potential, then jump off as a high-energy spark discharge to a nearby less charged surface. The spark may be hot and prolonged enough to ignite nearby hydrocarbon vapors present above the lower explosive limit (LEL). This potential shall be managed by safely dissipating static charges, and through proper grounding, when handling flammable products.

10.1.2. PERSONAL ATTIRE (D4057, SECTION 5.4.2)

Footwear or clothing, capable of causing sparks, for example, clothing made of synthetic materials, should not to be worn during fuel handling activities in which flammable vapors are likely to be present. Sampling should not be carried out during periods of atmospheric electric disturbance or hail storms. To ground any static charge on their body, the individual performing the handling should touch a grounded structure prior to handling fuel.

10.2. VAPOR HAZARDS

All testing must be done in compliance with Federal, State, and local site-specific fire safety protocols as well as applicable NFPA codes and standards.

10.3. ICE BURNS/FROSTBITE

This document does not replace or supersede any local or site requirements related to ultra-low temperature exposure. Frostbite or the formation of ice crystals in human tissues occurs at -4 °C (25 °F) or lower. This test requires cold soaking test articles at temperatures from -10 to -58 °C (14 to -72 °F). The testing requires handling these chilled samples at temperature and exposure to a chilled environment (test chamber). Unprotected contact with items chilled to less than -4 °C (25 °F) for periods of time longer than a few minutes can cause frostbite and ice burns.

10.4. PERSONAL PROTECTIVE EQUIPMENT

This document does not replace or supersede any Federal, State, local or site-specific requirements related to personal protective equipment. Proposed test fuels may be substantially different than traditional petroleum-based aviation gasoline. These test fuels should not be assumed to be equivalent in hazards to "gasoline".

1) Standard PPE – Technicians and test engineers are advised to familiarize themselves with the safety data sheets (SDS) for all of the fluids under test. Individuals are recommended to use at a minimum safety glasses or goggles, chemical resistant gloves as suited to the fuel chemistry, and lab coats or aprons. Note that fire rated lab coats MAY NOT also be chemical resistant. Note that chemical laboratory coats may be a synthetic material and may create static electric sparks. Closed toed, non-charge isolating footwear is also recommended. The chemical properties of the test fuels may require gloves of differing levels of protection. For example, while nitrile gloves may suffice for 100LL aviation gasoline, nitrile may not be sufficient for protection against other chemicals that may be in the test fuels. The test fuels may not yet have undergone hazard and toxicity testing in humans.

2) Component Run PPE – Technicians and test engineers must use appropriate hearing protection during test loop runs.

10.5. LOW TEMPERATURE EXPOSURE PPE –

Respective to the cold exposure, technicians and test engineers are advised to consider the necessary personal protective equipment specific to ultra-low temperature exposure. Examples of recommended PPE include but are not limited to gloves with sufficient conductive protection to permit handling samples of -58 °C (-72 °F) for at least 30 minutes, a laboratory apron with insulative properties, and a face shield. These should be worn over standard laboratory PPE or if

necessary, in a place of, recognizing the chemical resistance may be less than that of standard PPE.Liquid Nitrogen

This document does not replace or supersede local health and safety requirements for the handling and use of liquid nitrogen (LN2). In lieu of other requirements, safe handling of LN2 requires at a minimum the following.

1) Hand protection and goggles (not safety glasses) are to be worn when dispensing and handling liquid nitrogen. When handling large quantities, a full-length apron minimizes the chance of a spill going into shoes.

2) LN2 becomes gaseous nitrogen, and the nitrogen gas displaces oxygen in closed areas to the point where there is not sufficient oxygen to support life. Ensure proper ventilation is used in areas where LN2 can escape into the air. Cold nitrogen gas is heavier than air, so the risk is greatest near the ground.

3) Do not store container(s) of LN2 in a cold room or any other location where a person could physically enter an anoxic atmosphere. Cold rooms have no air changes and a person entering a room with elevated nitrogen in the air can quickly pass out and then die within several minutes of entering.

11. PRE-TEST REQUIREMENTS

This test plan has been developed based on the representative hardware of the six types of engines and airframes, and are designated as loops. These six loops; 1) RSA, 2) Continental, 3) Textron, 4) Piper / Light GA, 5) Rotorcraft, and 6) Cirrus; were used successfully in previous low temperature flowability tests and have been vetted by participating industry representatives. This is one means of compliance to this test plan.

A testing organization may elect to use alternative hardware or test cell configurations. In the case alternative means of compliance are selected, additional approval from the AFPO and potentially aviation industry manufacturer representatives will be required. Additional pre-test requirements are provided to validate alternative test cell configurations are sufficient. This additional validation:

1) Demonstrates the configuration can reach and maintain the test temperature with minimal temperature rise from fuel tank inlet to test exit. Fuel temperatures may rise through a cycle but shall return to the test temperature at the fuel tank.

2) Demonstrates the ability to reliably provide fuel to the rig at specified pressures and flows, and to provide fuel flow and pressure measurements at specified locations during the test.

3) Demonstrates that all components actuate and operate as required throughout the entire test.

11.1. TEST STAND INSTALLATION

It is permissible to construct test stands with the hardware from multiple loops on a single physical stand to facilitate testing multiple loops simultaneously. The installation of multiple loops must be such that each test loop is fully self-contained including the fuel supply and fuel pumps.

While no attempt is made to control the component temperatures as the fuel flows from the tank, through the components, and back to the tank during the testing, the temperature of the reservoir tank is to be controlled. The temperature of the fuel leaving the reservoir tank and into the test loop must be maintained to the target temperature +/- 1 °C. Natural fuel heating may occur as the fuel passes through pumps and components, and while methods should be used to minimize this heat rise, for example the use of an environmental chamber, the increasing fuel temperature is acceptable as the fuel passes through the component loop. Once the fuel is returned to the reservoir, an LN2 heat exchanger is used to return the reservoir fuel to the target temperature. The entire stand shall be installed in the environmental chamber to minimize temperature increases during testing. The actual fuel pumps and motors may be installed such that they are located outside of the environmental chamber to minimize the pumps' and motors' contributions to heat loads within the chamber.

11.1.1. TEST RIG CONSTRUCTION

Each of the six loop layouts are shown schematically in Appendix B. Rig construction shall comply with the individual schematics with respect to orientation and directional flows.

Figure 1 shows an example flow rig with two separate loops installed on one cart. Individual gauges are for pressure monitoring. Each of the two loops has a dedicated fuel tank in the rear. When the environmental chamber is closed, the fuel pumps and motors are outside of the chamber. (Note for purposes of clarity in Figure 1, when installed in this particular chamber, the top shelf of the cart shown is sealed in the cryogenic chamber, and the bottom shelf with the motor and pumps is below and external to the cryogenic chamber.)

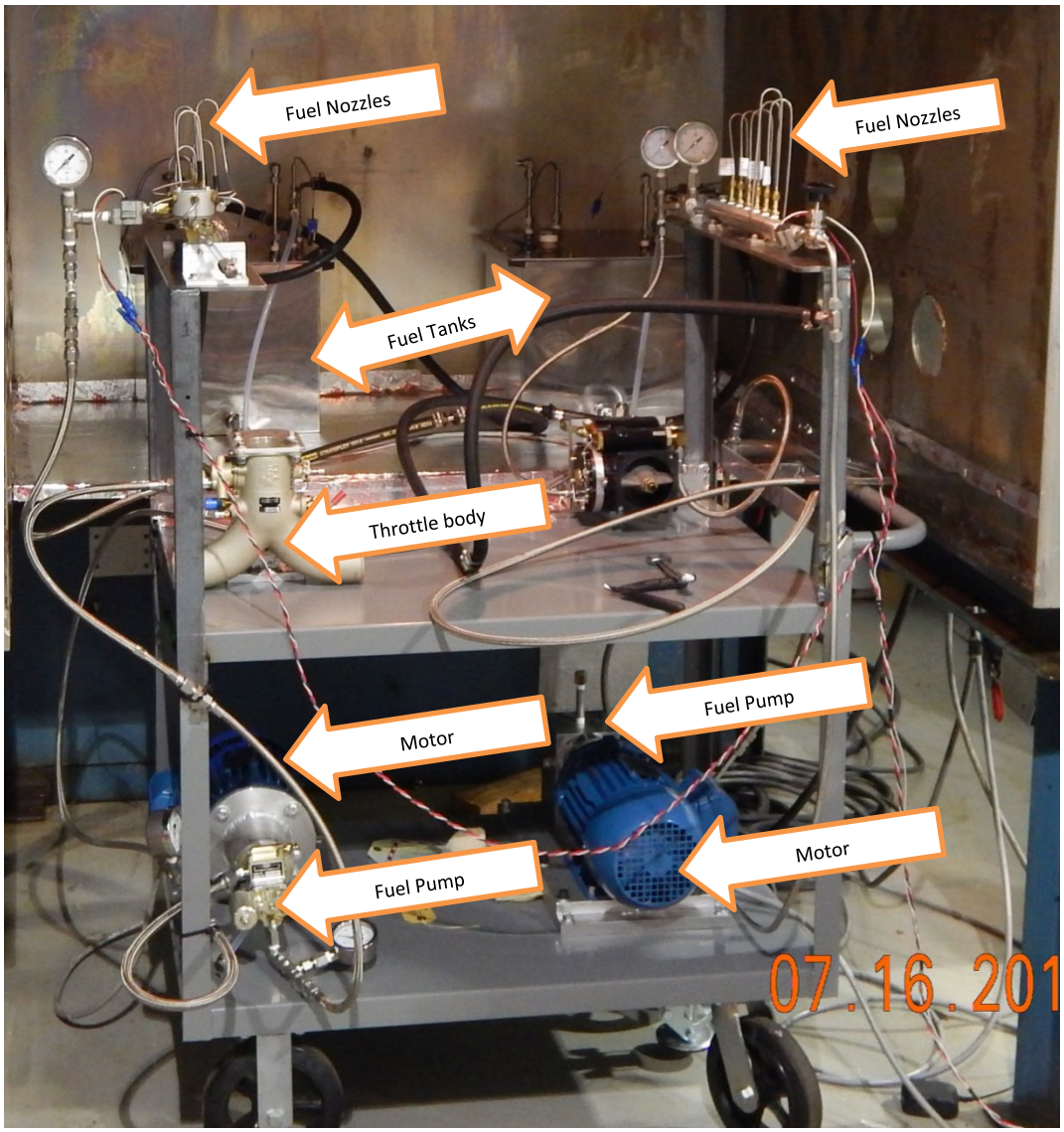


Figure 1 - Example Rig Cart with Two Loops; Continental (left) and RSA (Right)

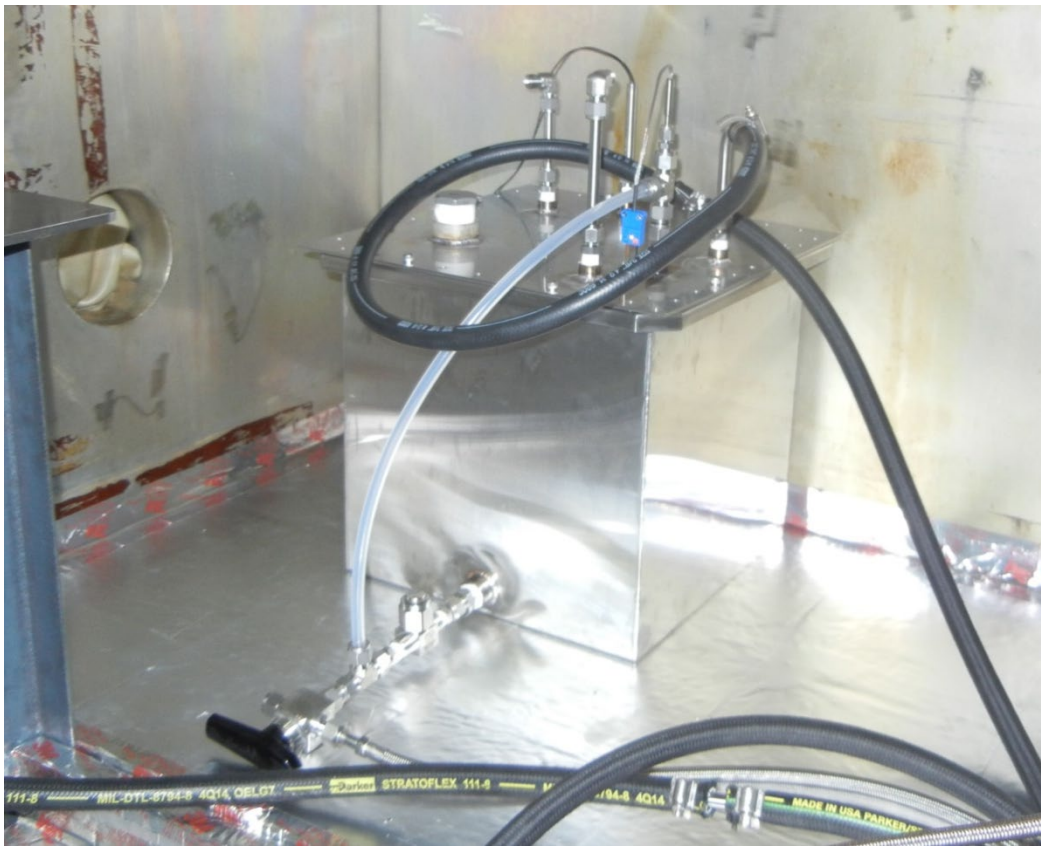


Figure 2 - Example Rig Supply Fuel Tank

Figure 3 - Example Fuel Nozzle Installation

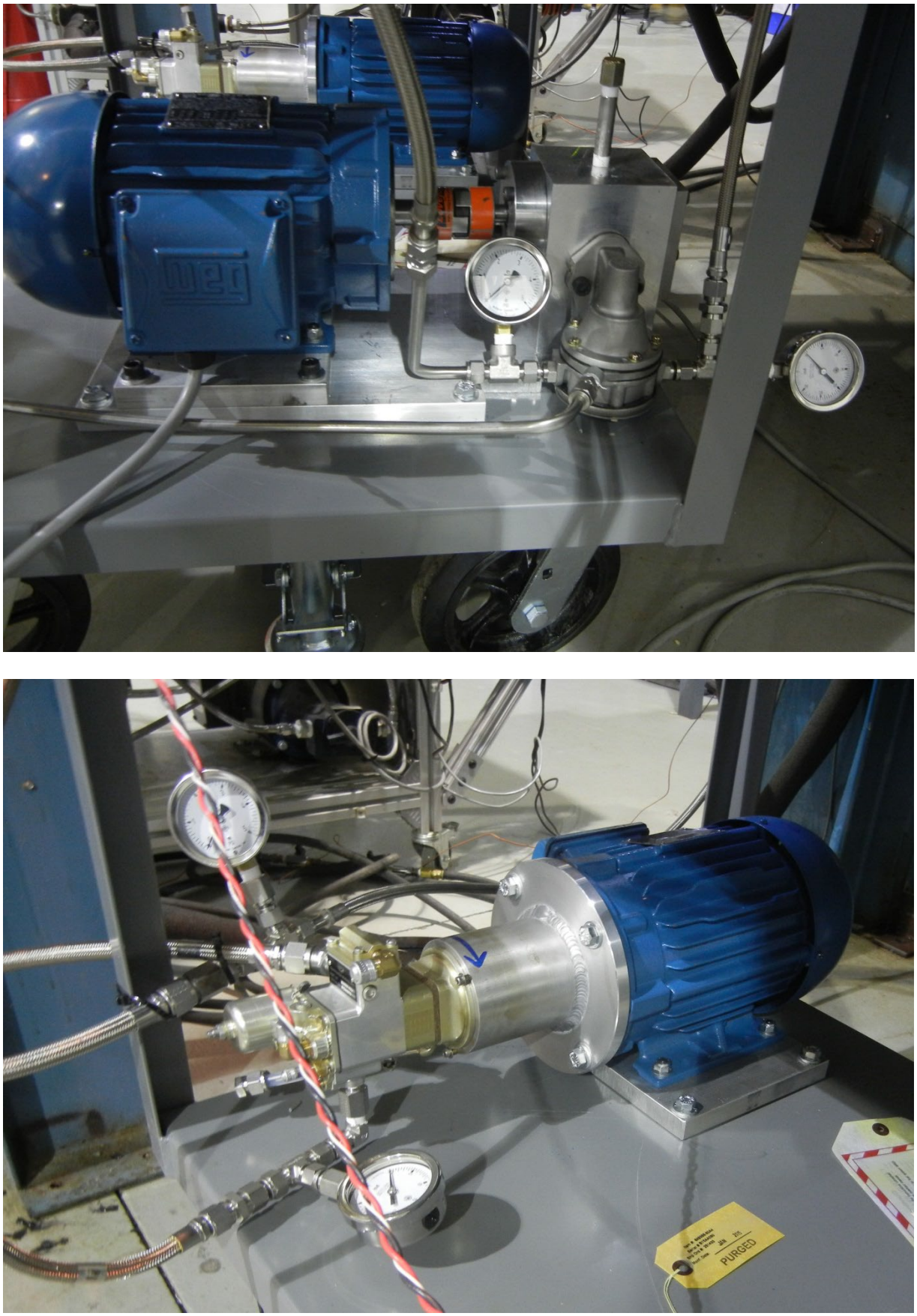


Figure 4 - Example Fuel Pump Motor and Fuel Pump (Note: pressure gauges ahead and after pump)

11.1.2. COMPONENTS

All components shall be mounted in accordance with generally accepted industry practices. While not specifically required, all components should be mounted in a similar manner and orientation to those typically encountered in use. Mounting positions other than those encountered on the aircraft may introduce operational instabilities unrelated to the fuel under test.

All components shall be installed in compliance with the schematics provided in Appendix B. These schematics mimic the flow path of the represented loop and have the components in the order typically encountered in the aircraft. Caution is recommended with respect to the use of steel fittings into aluminum components. Thermal expansion may cause cracking of the aluminum components even on tests as brief as the ones in this procedure.

Prior to the initial testing, the designated FAA representative shall inspect the installation of the components in the test facility for conformance with the requirements and specifications of this test plan. Conformance of facility instrumentation with calibration requirements may also be reviewed by the designated FAA representative.

11.1.3. FUEL LINES

Fuel lines shall be standard aircraft rigid and flexible fuel lines. Rigid lines for primary fuel flow are typically aluminum or stainless steel. Copper is not recommended for this test. Flexible lines of aviation and aerospace quality, should be verified to be certified to the temperatures of the tests, and like all the components, should have FAA 8130-3 certification. Lines shall be fitted with appropriate AN fittings for connection to the hardware components. Components shall be connected together by these fuel lines in compliance with specified installation requirements, or with standard industry practices where no requirements are provided. Note, not all of the ports on a component may be used. These ports may be capped/plugged.

11.1.4. AIR LINES

The use of Teflon™ (PTFE) tubing is recommended. Route lines from a warm regulator to the RSA ram air pressure sensing port. Dry air or nitrogen gas must be used. Any moisture in the air sensing system causes ice blockages. Any air lines or nitrogen lines for the RSA ram air sensing should be purged with dry air or dry nitrogen for 5 minutes prior to the cold test. The RSA static air sensing port shall be left open to the environment.

11.1.5. FUEL TANKS

Individual fuel tanks shall be used for each loop and for each fuel tested. Multiple loops run simultaneously shall not use the same reservoir. In the event of a

problem with the fuel, a component, or the test apparatus, commingling of the fuels makes identification of the problem difficult or impossible.

Each tank must be capable of holding sufficient fuel to fill and run a test, typically eight (8) gallons, and shall be installed in a manner to permit cooling of the fuel. Too little fuel results in either the inability of the LN2 heat exchanger to keep the fuel at the target temperature, or results in a stressing of the fuel as the fuel is re-cooled upon return to the reservoir. Repeated stressing of the fuel as it is re-cooled can cause shock cooling and cause some fuels to break down in a manner not typical of aircraft use. Cooling of the fuel should be accomplished by using a stainless-steel heat exchanger charged with LN2.

All fuel tanks are to be “gravity fed” from the reservoir and into the respective aircraft boost pumps or engine fuel pumps in the test loops. The fuel tank shall maintain a head rise over the pump inlets of at least -0.75 to +1.0 psi regardless of the fuel flow. Higher gravity feed head pressures are permitted. To enhance pump priming, ensure the fuel level is at least 12 inches above the fuel pump inlet fitting.

11.1.6. Fuel Pump and Motor

The aircraft boost pumps and the engine fuel pumps are used to provide fuel flow and pressure to the test loops. The aircraft boost pumps typically have an integral electric motor or drive; however, the engine pumps require an external mechanical or motor drive to actuate the pumps. These mechanical drives must mimic the engine accessory drive case in order to provide the proper pump RPM or pump actuation.

For both the RSA and the Continental loops, a separate fixture to actuate the pumps in a manner replicating the engine accessory case drive is required. Any number of drive fixture designs is possible as long as the speed and range of motion of the pumps can be maintained. It is recommended the pumps and the motors be located external to the environmental chamber to minimize heating the test components within the chamber. See paragraph 11.1.1 and Figure 1.

11.1.7. Fuel Filters

Because the test rig is not equipped with fuel filters, it may be desirous to install standard 140 micron finger filters just in front of the fuel pump to protect the fuel pump from catastrophic part failure and concomitant debris. During original FAA testing such a filter could experience plugging due to ice formation unrelated to the test. It can also be advantageous if there is a question regarding the test fuel, and troubleshooting of the fuel is required. In such a case, the finger filter should be removed, the removal for cause documented, and testing resumed. While not required to run the test, the addition of these finger screens can be invaluable if anomalies occur during the cold testing.

11.2. Pre-Test Validation

Prior to data collection testing, each test flow rig shall be operated on a D910 compliant aviation gasoline to confirm operation, control, and data collection. This test is used to identify any issues with the set-up prior to actual testing.

11.2.1. ALTERNATIVE TEST FLOW RIG SET UP

The following information is one means of compliance with the intent of the testing. It is possible that other test layouts or individual components different from those presented here may be acceptable. Prior to the purchase of, installation, or rig build-up of alternative means of compliance, the tester is required to procure approval from AFPO. Alternative installations or rig build-up requires validation of correct operation of the installed components on a D910 compliant 100LL. This validation does not contribute to the test data. This validation may be accomplished by demonstrating acceptable performance through an entire test cycle at each of -20, -40 and -58 °C.

11.3. PRE-TEST INSPECTIONS

Ensure all components are new and where available have an appropriate FAA Form 8130-3 Certificates of Conformance or other appropriate FAA documentation.

A logbook shall be maintained for the test with all starts, stops, test time, total time, all loop pressures, all loop flows, engine power setting being simulated (idle, 80%, or full power), system maintenance, and other notes logged as appropriate.

Anomalies, replacement parts, troubleshooting, and other unplanned events shall be recorded in the log.

11.4. SPECIMEN IDENTIFICATION

It is recommended that any vials/containers to be used to collect specimens be marked with unique specimen identifiers which are permanently affixed to the specimen vials. The selected means of marking must not interfere with the closure of the specimen vial, and must not be removed by accidental contact with the sample material. Marking that has proven problematic in previous testing includes labeling the glass surface of the vial with permanent marker (i.e. Sharpies™), as the test fluids including aviation gasoline removes the markings. The use of taped labels has been successful as long as the marks were made prior to sampling and the tape was placed on the vial prior to use. Other successful methods include the attachment of a pre-marked metal tag wired to the vial as long as the attaching wire is of a gage that does not interfere with the threaded cap.

11.5. PRE-TEST BASELINE FUEL DATA

Specimens in this test plan are comprised of liquid fuels collected from the unleaded test and the D910 100LL fuel tanks immediately before conditioning the fuel and after a test run. A minimum of 50 ml shall be collected into glass jars

with either Teflon lined lids or with a layer of foil over the mouth. The specimen is collected from fuel at the test temperature. The fuel shall be either tested immediately per ASTM D6304 Karl Fischer, or shall be sealed and stored at the collection temperature until testing can be performed.

11.6. LABORATORY NOTEBOOK

Either a bound notebook or digital notebook shall be maintained for any testing. Technicians shall record each individual specimen's unique identification, any lot or certification information, and all corresponding pre-exposure data. Each test and test method, as well as any equipment identification shall be recorded. The test results report shall document the manufacturer and model of any analytical equipment used. Information related to the instrument calibration or validation shall be recorded.

This notebook shall also be used to record any start times and dates, test conditions such as temperature, visual observations, and the time and date of test terminations.

Anomalies, issues, troubleshooting, unplanned events, and any other observations shall be recorded in the notebook. Final test data shall be recorded and positively connected to the appropriate pre-exposure data.

12. TEST FACILITY & EQUIPMENT

12.1. TEMPERATURE CONTROLLED ENVIRONMENTAL CHAMBER

The environmental test chamber used to conduct cold flow testing shall consist of a space with sufficient volume to completely contain the assembled test rig(s), with the exception of the fuel pump and motor (Figure 5), and to permit operation of the test rig(s) per the specified protocol. Operation of all six rigs simultaneously is not required. The chamber shall be capable of maintaining the test temperatures within the chamber volume although it is not required to maintain the individual components at the test temperature at all times throughout the test. As long as the fuel reservoir outlet remains at the target temperature, the temperature may vary as the fuel moves through the loops. The hardware (rigs) shall be cold soaked within the environmental test chamber at the target temperature prior to the flowing test. Once testing is commenced, the chamber shall remain at the target temperature.

The environmental test chamber shall be capable of reaching and maintaining test temperatures of -20, -40, and -58 °C ± 3 °C (-4, -40, and -72 °F ± 5 °F). While continuous temperature recording of the test chamber is not required, a means of monitoring the actual chamber temperature shall be available.

Local fire safety regulations may limit the total volume of flammable liquids permitted within a space, especially in occupied locations. Each rig as presented

here requires a minimum of eight gallons of fuel to provide operation of the rig with sufficient heat sink capabilities to maintain fuel test temperatures.

Figure 5 - Example of Test Rig inside Environmental Chamber

12.2. FUEL TANKS AND FUEL CONDITIONING

12.2.1. FUEL TANKS

As many fuel tanks as test rigs to be operated simultaneously during a test are required. Each rig under test shall have a dedicated fuel tank for each of the test fuels (baseline 100LL and any unleaded fuel formulas). The same fuel tank may be used with the same fuel in tests that are run serially, however, if tests are to be run in parallel, multiple tanks are required, one for each loop under test, even when it is the same fuel. The volume of the tank shall be sufficient to flow the rig and maintain necessary heat sink. Alternative tank sizes require validation of sufficient temperature control over the entire test protocol and at all fuel flows.

12.2.2. FUEL CONDITIONING

A means of chilling the fuel to the desired temperature is required. One means of cooling the fuel is the use of a stainless-steel heat exchanger charged with liquid nitrogen. The heat exchanger is fitted internal to the fuel tank. This heat

exchanger also provides removal of the residual heat imparted to the fuel during testing. The rate of flow of the LN2 may be used to control the temperature.

12.3. Electronically Controlled and Monitored Component Control

Throughout the testing, means of controlling and monitoring individual fuel flows, fuel/air pressure, test cycles, component voltages/speeds/amperages, and cycle times on a per pump / per rig basis are required. This control and monitoring shall be maintained throughout the duration of the test run. Continuous data collecting is not required, but is desirable. A means of monitoring actual test conditions throughout a test is required. An example of a data collection sheet is provided in Appendix C.

A means of shutting down the system, especially in case of out-of-limits performance of any individual component, shall be provided.

12.4. Karl Fischer Moisture Meter – Coulometric

A Karl Fischer titrator and concomitant chemicals are required to determine the moisture content of the samples. Depending on the chemistry of the test fuel, reagents for aldehyde/ketone samples, or an additional oil dryer accessory may be required.

12.5. Instrument Calibration

Instrumentation used to measure and monitor parameters during the test shall be calibrated with traceability to a national standard, as appropriate. Instrumentation calibration records shall be made available to the FAA representative designated to witness testing prior to start of the test and shall be included in the final test results report.

13. Test Witnessing

Test witnessing is required for the collection and reporting of data collected in compliance with this test plan. This data is to be used by the FAA as part of their evaluation for fleet authorization. Part of the submitted test plan must be a means of test witnessing by an FAA authorized representative.

Testing performed in accordance with an approved test plan shall be witnessed by a representative of the AFPO or their designated representative. The extent of witnessing is at the discretion of the FAA; however, at a minimum the representative shall verify and witness the following segments.

1) Verify certificates of analysis are available for supporting samples as appropriate and for all test fuels

2) Verify instrument calibration/validation as appropriate

3) Inspect test set up (jars, specimen arrays, rigs, ovens, etc.

4) Verify pre-exposure data, record keeping and specimen control

5) Review test plan with test personnel

6) Witness test initiation

7) Witness fuel exchanges at the FAA's discretion and as appropriate

8) Witness test conclusion

9) Witness post exposure testing at the FAA's discretion and as appropriate

10) Verify testing in accordance with test plan

14. TEST PROCEDURE

To run a comparative test, the protocol is to run a system check fuel at room temperature. The rig will be cooled to avoid thermal shocking the hardware prior to each test run. The D910 baseline fuel will be run at each temperature beginning with -20 °C, then -40 °C, and finishing with -58 °C. After running the baseline fuel, the rig(s) are to be drained and purged with dry nitrogen. The entire test protocol with be repeated with the candidate fuel(s) at each temperature (-20, -40, and -58 °C). A D910 compliant system check fuel shall be run between different unleaded test fuels if multiple formulas are being tested. Note: while the check fuel may be introduced into the D910 aviation gasoline test cell fuel tank used for actual testing, each different fuel being tested must have a dedicated test cell fuel tank.

14.1. MATERIALS

1) ASTM D910 compliant aviation gasoline produced with the highest freeze point while still within specification

2) System check fuel - ASTM D910 compliant aviation gasoline without limit. Note: the use of the high freeze point D910 aviation gasoline may be used as a check fuel should volumes permit.

3) Unleaded candidate fuel(s)

14.2. TEST PREPARATION

14.2.1. TRANSFER FUEL

Transfer fuels to appropriate fuel tanks. Individual tanks are to be used for each fuel type.

14.2.2. AMBIENT WATER CONTENT

At the time of testing, collect an ambient specimen (as is) for baseline Karl Fischer moisture testing.

14.2.3. FUEL PRESSURE AND FLOWS

This protocol uses fuel flows (W_f) as the means of determining "power" settings. The fuel pressure is contingent on individual hardware output. Fuel flows at cruise power for the 360 to 500+ cubic inch families of engines (estimated at 80% of maximum fuel flow) is ~15 gallons/hour. Idle flow is ~ 3.5 – 4 gallons/ hour. Maximum fuel flow is ~ 20 gallons/hour. These values are typical. It is permissible to use more specific fuel flows for each design philosophy. The source for selected fuel flows must be documented.

Multiple locations for monitoring fuel pressure are indicated in each of the schematics in Appendix B. Fuel flow is measured using the Floscan flowmeter and the location of the flowmeter is indicated in each of the schematics in Appendix B.

14.2.4. SYSTEM TEMPERATURES

Bulk fuel temperature is to be measured at the fuel tank. The temperature within the environmental chamber shall be observable.

14.2.5. PUMP SPEED, VOLTAGE AND AMPERAGE

For the airframe loops, the fuel pumps are electrically driven pumps, not driven by the engine. The required shaft speed for the motor running the pump shall be set to the requirements of the individual fuel pumps; i.e., a pump requiring 24 volts shall be set to provide 24 volts. The monitoring of the motor speed (RPM), the voltage, and the amperage are a direct measure of the pump health.

For the injection system loops, the fuel pumps are mechanical pumps driven by the engine (motor). For these loops, the motor is replacing the rotational input from the engine. It is necessary to design and install a connection system from the motor into the mechanical pump. The motor is set to provide the required RPM required by the fuel pump for each power setting (idle, 80%, full). This is determined by fuel pump speed at 2700 RPM engine speed. The monitoring of the speed, voltage, and amperage is a measure not only of the mechanical pump's health, but also the health of the test rig.

In both cases, a change in the voltage/amperage required to provide unchanging speed indicates a change in the effort of the motor to provide the fuel flow. This provides information regarding the ability of each fuel to flow and as such differences in operational abilities of the fuel under test.

14.2.6. AIR PRESSURE

The only loop requiring an active air input is the RSA loop. Because of the manner in which the diaphragms within the RSA unit operate, it is desirous to provide an air pressure directly to the ram air pickup within the unit. It is permitted to use the static air port to sense the existing ambient air pressure. The ram air pressure is set to the specified pressure for the desired fuel flow at each power setting:

- Idle is 0 inH_2O ram air pressure
- 80% is 24.3 inH_2O ram air pressure
- Full is 27.2 inH_2O ram air pressure

14.2.7. RSA Injection Cycle Set-Up

For the RSA test, set the ram air pressure to the specified air pressure for the desired W_f (see 14.2.6) at each power setting (idle, 80%, full). Allow the static port to sense ambient pressure. Set the mixture control to full rich and make no further adjustments. Set the motor RPM to provide the required RPM (see 14.2.5).

14.2.8. Continental Injection Cycle Set-Up

For the Continental Motors test, no air pressure supply is required. Set the throttle valve position on the flow divider to that determined for each power setting (idle, 80%, full). Set the motor RPM to provide the required RPM (see 14.2.5) at the pump for at each power setting (idle, 80%, full):

- Idle at min throttle stop, 600 RPM
- 80% at 142-162 pph full rich, 2500 RPM
- Full at max throttle stop, 2600 RPM

14.2.9. Airframe Cycle Set-Up

For the airframe test loops, regulate the fuel flow (W_f) to the desired value for each power setting (idle, 80%, full) using the needle valve installed at the end of the loop just before the fuel reservoir return inlet. The boost pumps then supply fuel at their normal output, and the needle valve represents the restricted demand of the engine at each of the three power settings. Some boost pumps may be variable displacement, some may have an internal relief valve, and some may have a bypass return line to the fuel tank (reservoir). In all cases the needle valve simulates the flow demand of the engine.

14.2.10. 140-micron finger screens

The finger screens are used to collect any debris in the fuel loops that may remain from the construction of the loops, and to collect any contamination that may have

been inadvertently introduced into the fuel. The finger screens may also collect chemical components in the test fuel that separate when the fuel is subjected to extreme low temperatures. It is possible that the viscosity of the candidate fuel may increase to the point that the fuel flow is restricted by the finger screens. If this occurs, the finger screens may be removed, and the test records should note that the test is run without the finger screens and the reason for the removal of the finger screens.

14.3. DATA COLLECTION

All data; fuel flow, pressures, voltages, amperages, speeds, tank temperature shall be collected every ten minutes or at the beginning, middle, and end of a cycle depending on the cycle duration. Changes in readings indicate a change in the fuel flow through the loop.

14.3.1. FUEL PRESSURE AND FLOWS

The fuel pressure for a given fuel flow is contingent on individual hardware output. Fuel flows at cruise power for the 360 to 500+ cubic inch families of engines (estimated at 80% of maximum fuel flow) is ~15 gallons/hour. Idle flow is ~ 3.5 – 4 gallons/ hour. Maximum fuel flow is ~ 20 gallons/hour.

Multiple locations for monitoring fuel pressure are indicated in each of the schematics in Appendix B. Fuel flow is measured using the Floscan flowmeter and the location of the flowmeter is indicated in each of the schematics in Appendix B. Changes in fuel pressure at a given location shall be noted and reported.

14.3.2. SYSTEM TEMPERATURES

Bulk fuel temperature is to be measured at the fuel tank (reservoir). The bulk fuel temperature shall be maintained at the test temperature ± 3 °C (5 °F).

14.3.3. PUMP VOLTAGE, AMPERAGE AND SPEED

The speed of the pump, as well as the pump voltage and amperage shall be monitored to maintain the required fuel flows. Changes required in these settings to maintain fuel flow shall be recorded and reported.

14.3.4. PNEUMATIC SYSTEM PRESSURE (RSA)

Monitor the supplied air pressure to the ram air port on the RSA unit.

14.4. COLD FLOW TEST PREPARATION

1) Before each loop(s)' test, run the loop(s) at room temperature (approx. +21.1° C [+70 °F]) on system check fuel to test the system and verify operation.

2) Drain the system check fuel, purge loop(s) with dry nitrogen and refill the loop(s) with ASTM D910 baseline 100LL.

3) Chill fuel in the tank and in the filled, but non-flowing loop(s) to -20 °C (-4 °F) and allow the temperature to stabilize. This stabilization period will be determined by the characteristics of the rig(s) but has been found to be approximately eight (8) hours. Previous testing has found it conducive to allow the stabilization to occur overnight.

14.4.1. ENGINE LOOP SETTINGS (LOOPS #1 (RSA) AND #2 (CONTINENTAL))

For the RSA system: for each run, record whether the run is Idle, 80% power, or 100% power.

1) Set the pump RPM for the proper power setting.

2) Set the pneumatic pressure to the fuel servo for the proper power setting.

Controlling the pump RPM and Pneumatic pressure should keep all servos in regulation. It will be necessary to obtain the ram air vs. servo venturi pressure curve to properly set the RSA system fuel flows.

For the Continental system: for each run, record whether the run is Idle, 80% power, or 100% power.

1) Set the pump RPM for the proper power setting.

2) Set the throttle to the proper position for the desired power setting.

14.4.2. AIRFRAME LOOP SETTINGS (LOOPS #3, #4, #5 AND #6)

1) Turn on the airframe boost pump.

2) Adjust the needle valve at the reservoir return inlet to get the desired idle, 80%, or full fuel flow.

14.5. COLD FLOW TEST EXECUTION FOR INJECTOR SYSTEMS (LOOPS 1, AND 2) – BASELINE 100LL

The assumption with the injection system test is that the worst case is start up after cold soak from an engine in feathered condition (no pre-heat possible). After 20 minutes, the engine heat is expected to have warmed the systems, negating the effect of the cold fuel from the aircraft fuel tank.

14.5.1. CYCLE 1

1) Run system at idle flow for 10 minutes

2) Perform excursion to full power flows for 5 minutes.

3) Drop and run at 80% power flows for 20 minutes

4) Drop and run at idle flow for 10 minutes

14.5.2. CYCLE 2

5) Perform excursion to full power flows for 5 minutes.

6) Drop and run at 80% power flows for 20 minutes

7) Drop and run at idle flow for 10 minutes

14.5.3. CYCLE 3

8) Perform excursion to full power flows for 5 minutes.

9) Drop and run at 80% power flows for 20 minutes

10) Drop and run at idle flow for 10 minutes

11) Shut down fuel flow

12) Reduce temperature to next temperature and allow to stabilize (See 14.4, Step 3.

13) Repeat 14.4.1 to 14.4.3 for the next temperature until all desired test temperatures have been run for three cycles on the baseline 100LL.

14) Collect a fuel sample for Karl Fischer analysis from reservoir tank sump

15) Collect samples from the 140 micron finger screens. (Install new screen and put old finger screen in specimen jar with finger screen fuel if this is more convenient.

14.6. CANDIDATE FUEL PREPARATION

14.6.1. DRAIN AND PURGE

1) Warm the system back to approximately room temperature.

2) Drain the previous fuel, typically D910 baseline 100LL.

3) Purge the loop(s) with dry nitrogen

14.6.2. TEST PREPARATION

1) Switch fuel tanks

2) Fill loop(s) with UL100 test fuel

3) Chill fuel tank and filled loop(s) to -20 °C (-4 °F) and allow to stabilize (See 14.4, Step 3)

14.7. Cold Flow Test Execution – Candidate Fuel

1) Repeat 14.5.1 through 14.5.3 for each temperature with the unleaded test fuel.

2) Collect the fuel sample from reservoir tank sump for Karl Fischer analysis.

3) Collect samples from the 140 micron finger screens. (Install new screen and put old finger screen in specimen jar with finger screen fuel if this is more convenient.

4) If a second test fuel is to be tested, flush the system with the 100LL system check fuel and purge with dry nitrogen prior to switching fuels.

14.8. Cold Flow Test Execution for Airframes (Loops 3, 4, 5, and 6) – Baseline 100LL

The test profile for the airframes is representative of a generic aircraft flight and thus much longer than the profile for the injection systems.

14.8.1. Cycle 1

1) Run system at idle flow for 10 minutes.

2) Perform excursion to full power flows for 5 minutes.

3) Drop and run at 80% power flows for 120 minutes (2 hours).

4) Drop and run at idle flow for 10 minutes.

5) Cycle the fuel selector valve from input port 1 to input port 2 (simulate changing fuel tanks.)

6) Shut system down for 15 – 30 minutes.

14.8.2. Cycle 2

7) Run system at idle flow for 10 minutes.

8) Perform excursion to full power flows for 5 minutes.

9) Drop and run at 80% power flows for 120 minutes (2 hours).

10) Drop and run at idle flow for 10 minutes.

11) Cycle the fuel selector valve from input port 1 to input port 2 (simulate changing fuel tanks.)

12) Shut system down for 15 – 30 minutes.

14.8.3. CYCLE 3

13) Run system at idle flow for 10 minutes.

14) Perform excursion to full power flows for 5 minutes.

15) Drop and run at 80% power flows for 120 minutes (2 hours).

16) Drop and run at idle flow for 10 minutes.

17) Cycle the fuel selector valve from input port 1 to input port 2 (simulate changing fuel tanks.)

18) Shut down fuel flow.

19) Reduce temperature to next temperature and allow to stabilize (See 14.3, Step 3.

20) Repeat 14.4.1 to 14.4.3 for the next temperature until all desired test temperatures have been run for three cycles on the baseline 100LL.

21) Collect a fuel sample for Karl Fischer analysis.

22) Collect samples from the 140-micron finger screens. (Install new screen and put old finger screen in specimen jar with finger screen fuel if this is more convenient.

14.9. CANDIDATE FUEL PREPARATION

14.9.1. DRAIN AND PURGE

4) Warm the system back to approximately room temperature.

5) Drain the previous fuel, typically D910 baseline 100LL.

6) Purge the loop(s) with dry nitrogen.

14.9.2. TEST PREPARATION

4) Switch fuel tanks.

5) Fill loop(s) with UL100 test fuel.

6) Chill fuel tank and filled loop(s) to -20 °C (-4 °F) and allow to stabilize (See 14.3, Step 3).

14.10. COLD FLOW TEST EXECUTION – CANDIDATE FUEL

5) Repeat 14.4.1 through 14.4.3 for each temperature with the candidate test fuel.

6) Collect the fuel sample for Karl Fischer analysis.

7) Collect samples from the 140-micron finger screens. (Install new screen and put old finger screen in specimen jar with finger screen fuel if this is more convenient.

8) If a second test fuel is to be tested, flush the system with the 100LL system check fuel and purge with dry nitrogen prior to switching fuels.

14.11. TEST CONCLUSION

After all the fuels have been run at all of the temperatures, allow the system to warm to room temperature.

1) Drain the previous fuel, typically unleaded test fuel.

2) Purge the loop(s) with dry nitrogen.

3) Switch fuel tanks to the D910 compliant 100LL system check fuel.

4) Fill loop(s) with system check fuel and flow for 10 minutes at full fuel flow (W_f) flow to rinse the system.

5) Drain the system check fuel and purge loop(s) with dry nitrogen.

6) Disassemble the rig, capping each port on each component in preparation for component inspection.

14.12. DATA COLLECTION

Record and report all pressures, flows, speeds, voltages, and amperages throughout the test, at the start of the test set, prior to each step change in simulated engine speed (i.e., from idle to max flow), at least every ten minutes on long duration runs, and prior to shut down. Report if excessive torque is required to change the position of the fuel selector valves, or if the valves cannot be cycled.

14.13. POST TEST MEASUREMENTS

1) Test the moisture content of each fuel specimen.

2) Test the viscosity, density, and surface tension of each fuel specimen.

3) Visually inspect the 140-micron finger screens immediately upon removal and photograph any anomalous material in the screens. There is precedent for the collection of material which melts upon warming. Retain the 140-micron screens and any collected fluid for future analysis.

14.14. CALCULATIONS

No specialized calculations are required. Data tables showing the measured RPM, GPH, pump speed, and test temperature shall be prepared (See Appendix C for an example).

15. PASS/FAIL CRITERIA

Neither existing FAA CFR regulations, nor the existing fuel specifications, have a specific pass/fail criterion regarding cold flow performance. However, it is expected that a test fuel should be no more prone to variations than experienced by an ASTM D910 compliant aviation gasoline.

Greater instabilities or other statistical operational differences than those observed with 100LL should be considered grounds for concern as the existing engine/airframe designs may be sensitive to fuel flow instabilities or shifts in component operation.

16. TEST PERSONNEL

The testing source shall identify a single Point of Contact (POC) for conduct of this testing. This POC shall be equivalent to a Test Director who shall have the authority for oversight and supervision of those conducting the test. The identified POC shall have responsibility during the test for decisions regarding executing and integrity of the test. This local POC for the testing shall have the FAA point of contact clearly identified and contact information available.

The local designated POC is not a FAA designated representative, and does not have authority to witness testing for the FAA. While the FAA may choose to identify this person as a designated representative, this identification as such is solely at the discretion of the FAA. Any identification of the POC as the designated FAA representative for the purposes of witnessing tests must be made prior to any testing occurring.

17. TEST RESULTS REPORT

The objective of the testing specified is to generate data supporting a fuel formulator's participation in the FAA PAFI testing program with the intent of demonstration that potential changes in fuel flows and pressures across components remain within acceptable limits for the use of the offered fuels. The report documenting the test results pursuant to this Test Plan shall include the fuel certifications, supporting date, time, flow, pressure, and temperature data, notes and observations during the tests, results of any fuel specimen lab testing (i.e., Karl Fischer, etc.) test articles (by part name, part number, and serial number), copies of the FAA 8130-3 forms for the components, detailed and

dimensioned diagrams of the plumbing of the fuel loops. The report shall also include the identification of test equipment used by make and model, and evidence of equipment calibration or validation as appropriate. A table showing graphically the test results, compliance to the pass/fail criteria, and the actual test results shall be provided.

18. REFERENCES

In addition to the reference material of Section 5`, the following references are related to the testing described.

1) ASTM D910, “Standard Specification for Aviation Gasoline.”

2) ASTM D1298, “Standard Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method.”

3) ASTM D1331, “Standard Test Methods for Surface and Interfacial Tension of Solutions of Paints, Solvents, Solutions of Surface-Active Agents, and Related Materials.”

4) ASTM D4052, “Standard Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter.”

5) ASTM D4057, “Standard Practice for Manual Sampling of Petroleum and Petroleum Products.”

– END OF TEXT –

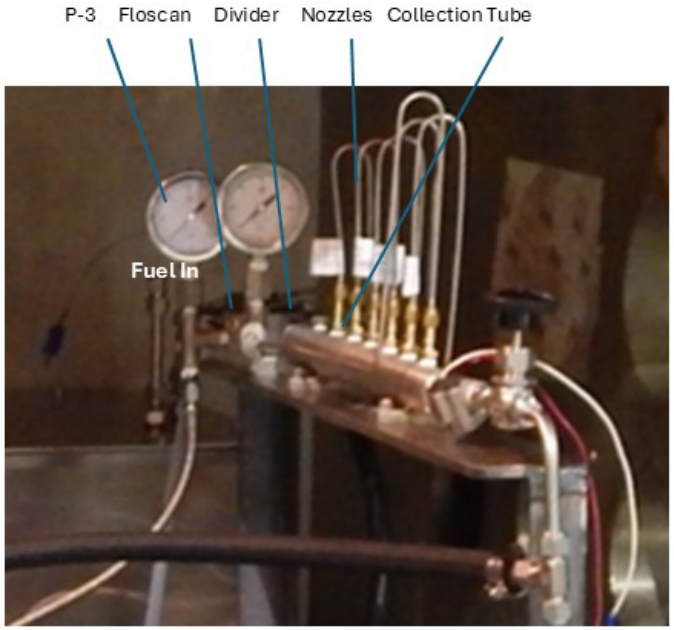
APPENDIX A
ADDITIONAL TEST FUEL COA REQUIREMENTS

PRE AND POST TEST FUEL ANALYSIS PARAMETERS

PROPERTY	TEST METHOD
Distillation	D86
Viscosity	D445
Surface Tension	D1331
Water reaction	D1094
Density	D4052
Moisture Content by Karl Fischer	D6304

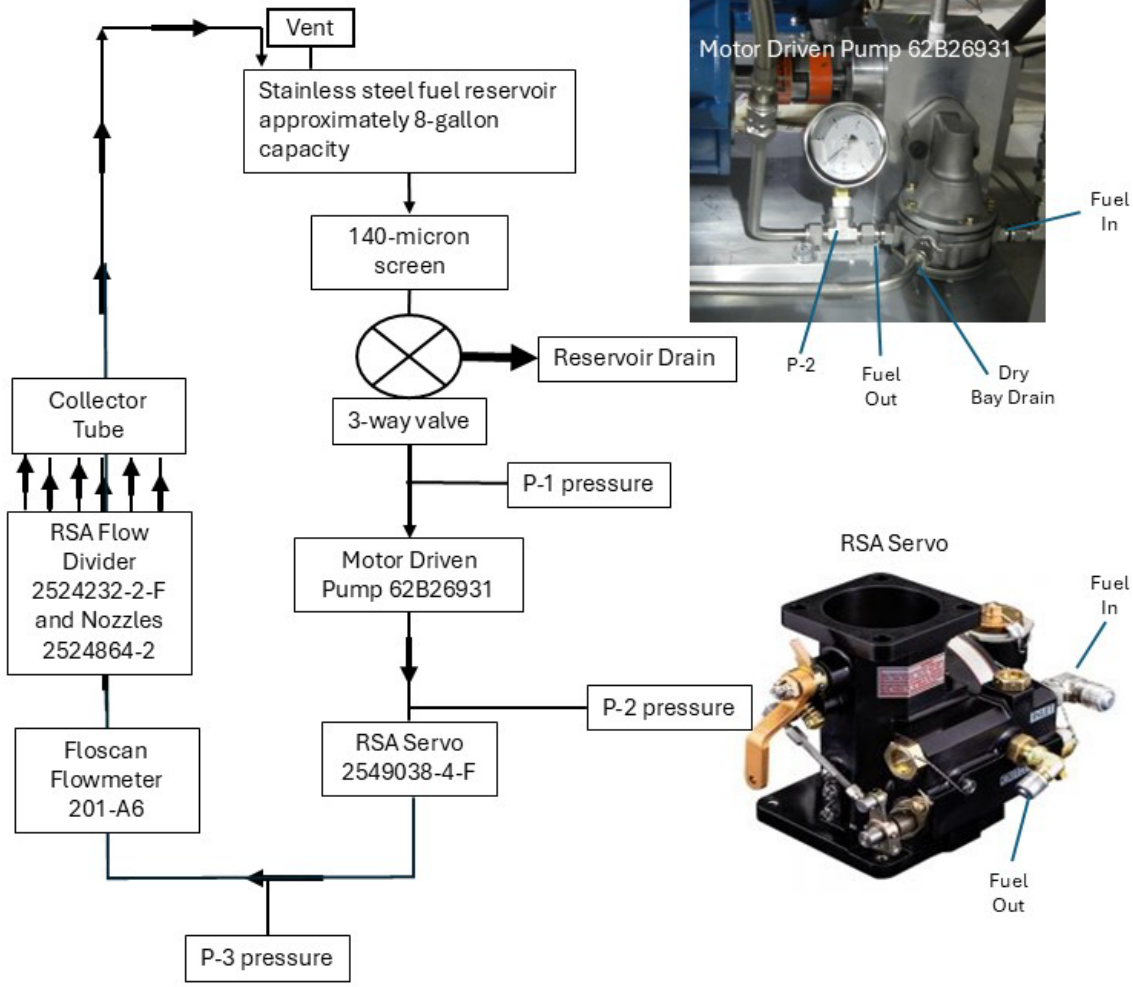
APPENDIX B
INDIVIDUAL LOOP SCHEMATICS

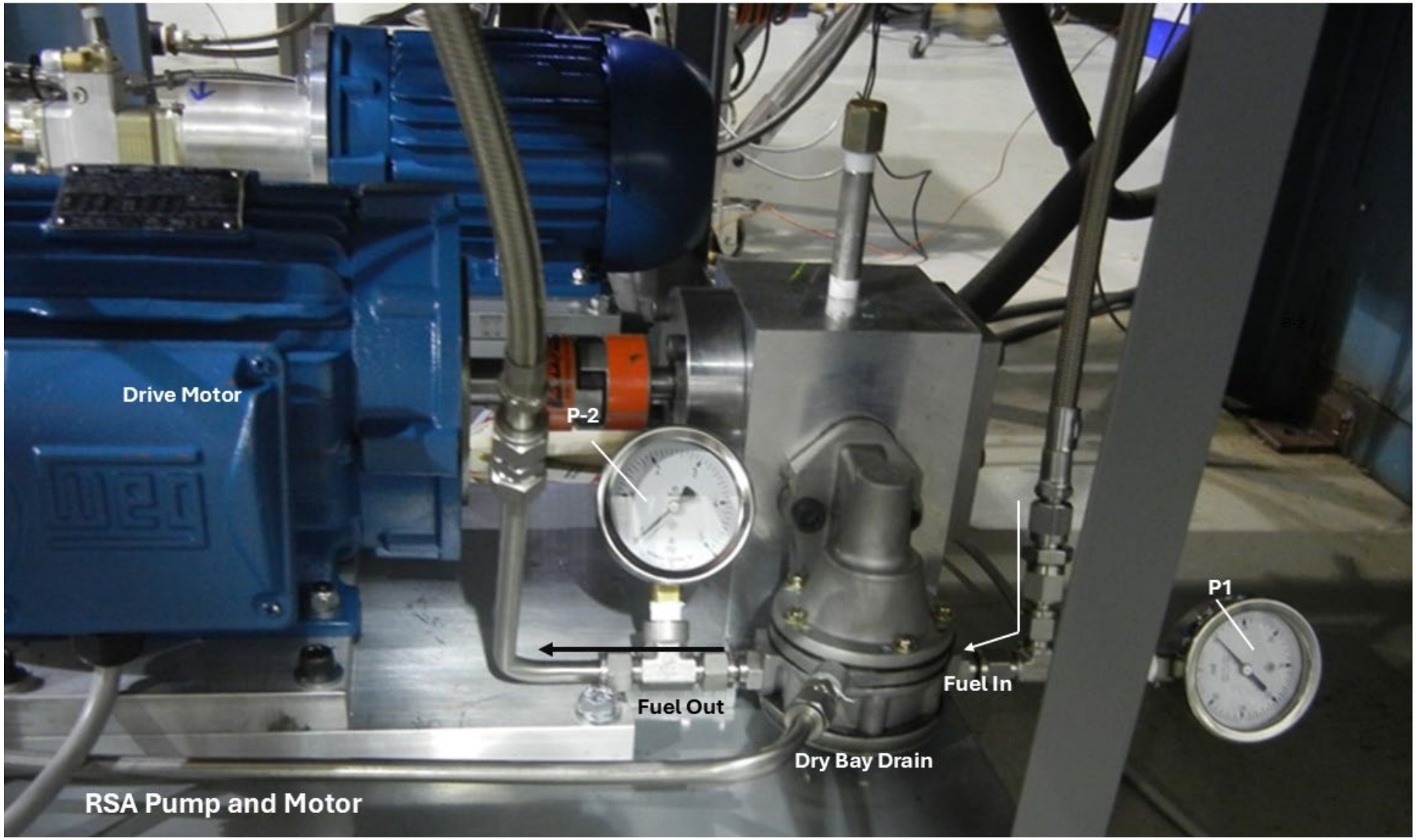
1) RSA Loop



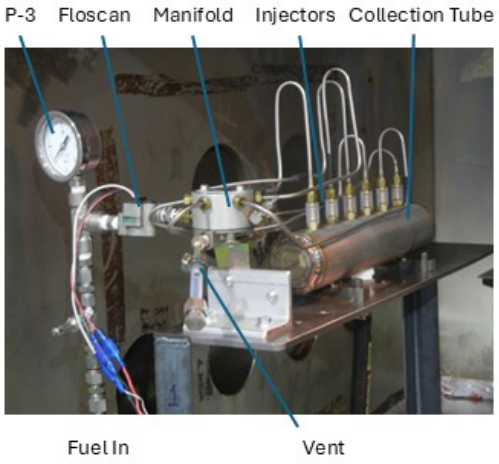
All hose sizes are -6 = 3/8" ID except vents and drains shall be -4 hose.
Turn the mixture control shaft on the RSA Servo fully clockwise (facing), against the stop, to set full rich flow.
Turn the throttle shaft on the RSA Servo fully counter-clockwise (facing), against the fixed stop, to set full throttle/fuel flow.
All pressure lines, except as noted: Braided Stratoflex 124. All low pressure lines from collector tube to reservoir chain of MIL-H-6000, Stratoflex 111 and Stratoflex 130. All fittings marked as Vents and Drains should be vented to atmosphere and routed to locations based on internal safety protocols.

RSA Loop as built schematic




Drive Motor
P-2
Fuel Out
Fuel In
P1
Dry Bay Drain
RSA Pump and Motor

2) Continental Loop



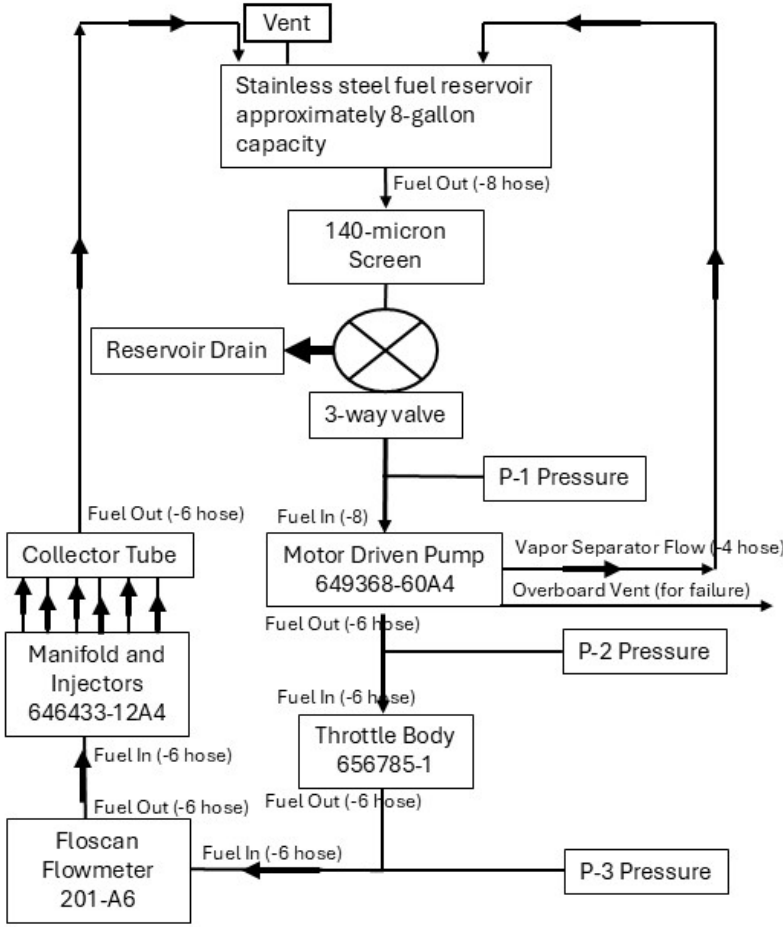
Turn the mixture control shaft on the motor driven pump fully counter-clockwise (facing), against the stop, to set full rich flow.

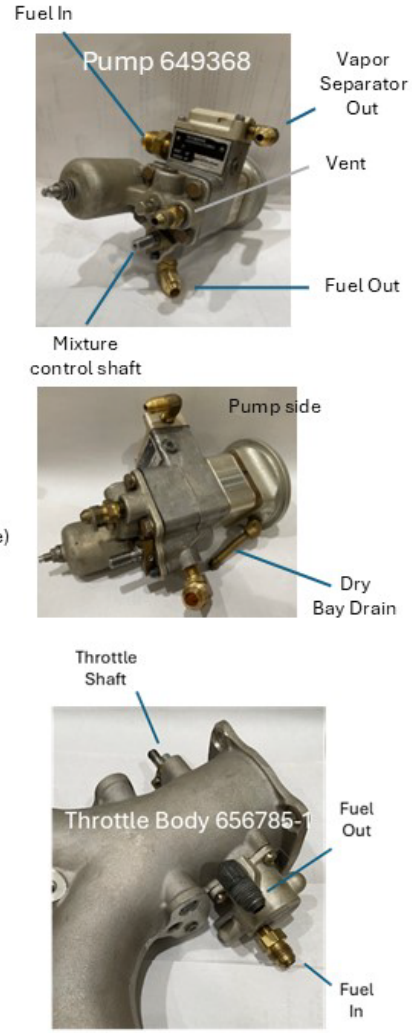
Turn the throttle shaft on the Throttle Body fully clockwise (facing), against the fixed stop, to set full throttle/fuel flow.

All hose sizes are indicated on the schematic. -4 = ¼" ID; -6 = 3/8" ID; -8 = ½" ID minimum. Vents and drains shall be -4 hose. Dash numbers noted on drawing.

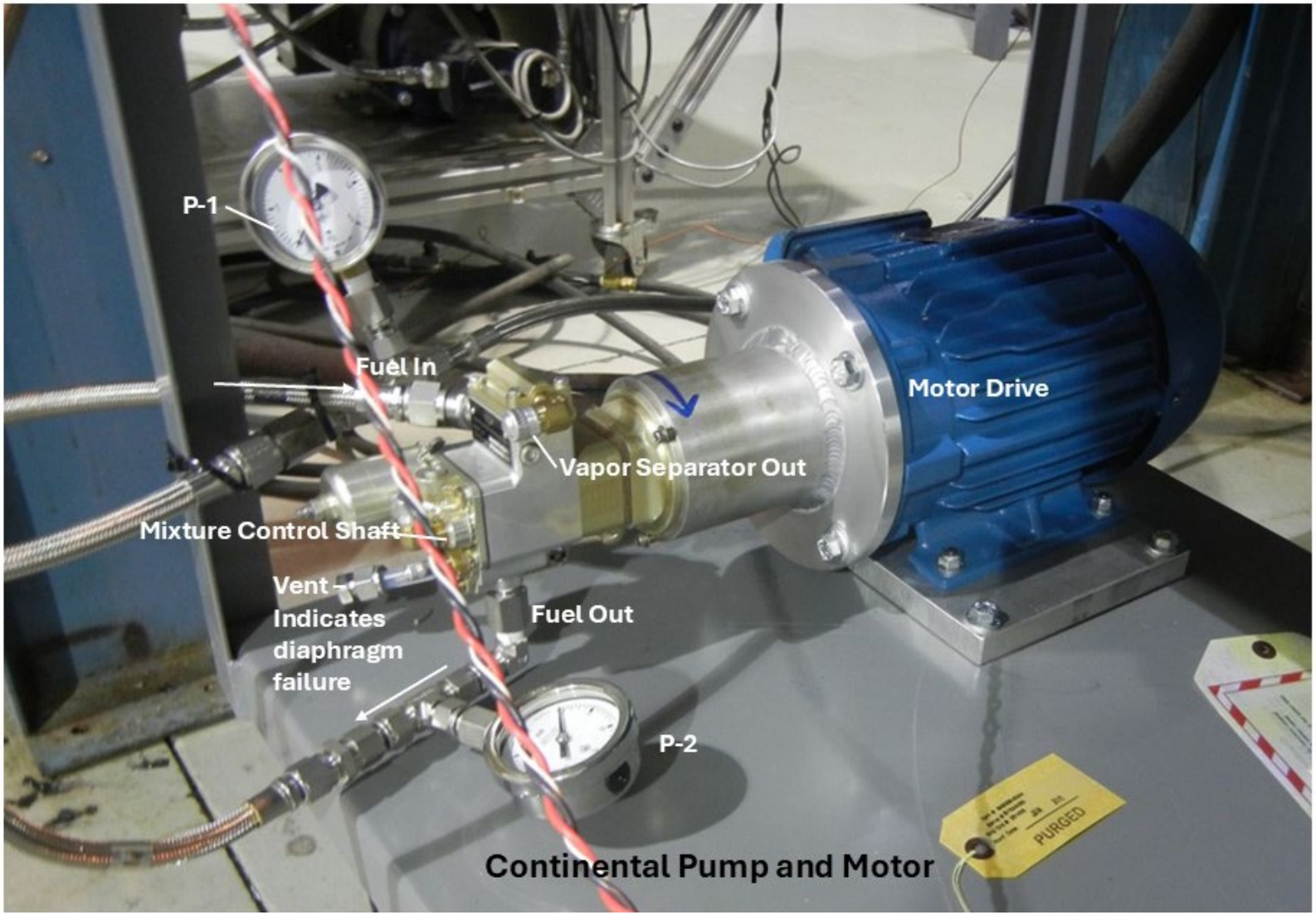
All pressure lines, except as noted: Braided Stratoflex 124. All low pressure lines from collector tube to reservoir chain of MIL-H-6000, Stratoflex 111 and Stratoflex 130. All fittings marked as Vents and Drains should be vented to atmosphere and routed to locations based on internal safety protocols.

Brown covered high pressure hose supplied by Continental Motors, to be placed between Throttle body and Floscan Flowmeter.

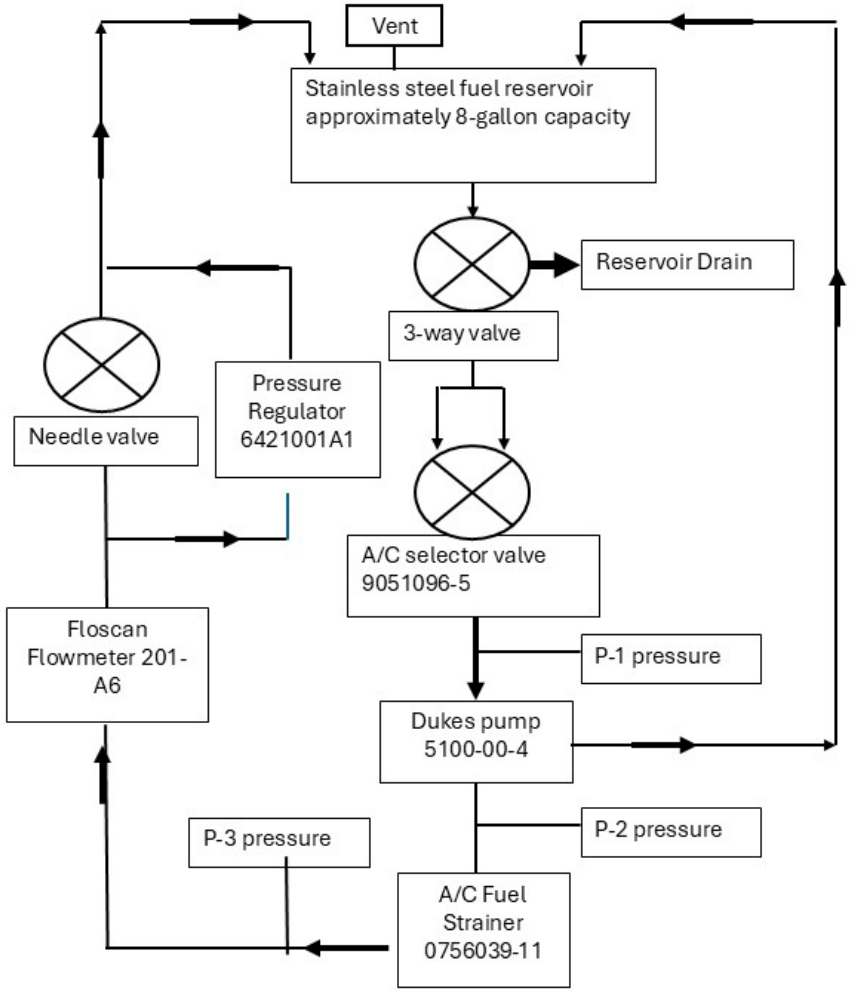


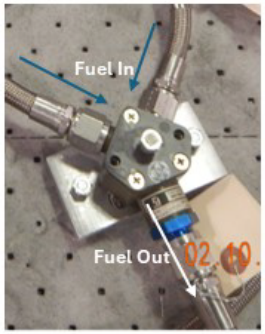


Continental Loop schematic


P-1
Fuel In
Motor Drive
Vapor Separator Out
Mixture Control Shaft
Vent – Indicates diaphragm failure
Fuel Out
P-2
PURGED
Continental Pump and Motor

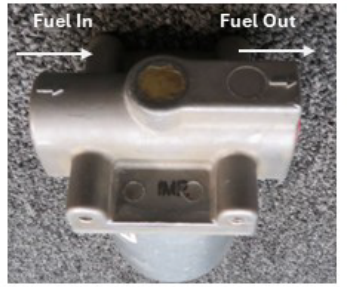
3) Textron Loop





Selector Valve 9051096-5

Dukes Pump 5100-00-4

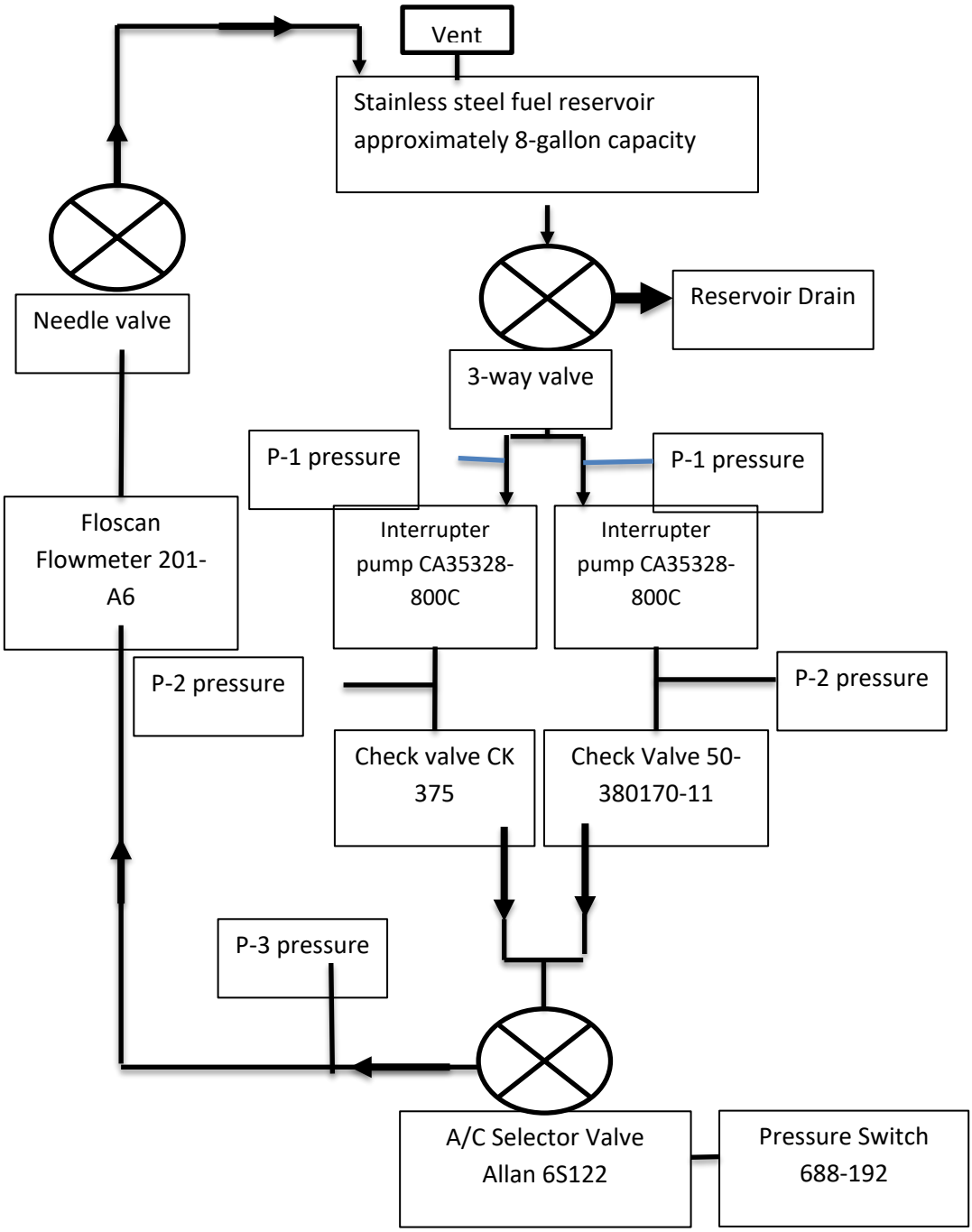


Fuel Strainer 0756039-1100

- All pressure lines to needle valve: Braided Stratoflex 124
- All lines from needle valve to reservoir chain of MIL-H-6000, Stratoflex 111, and Stratoflex 130

Textron Loop as built schematic

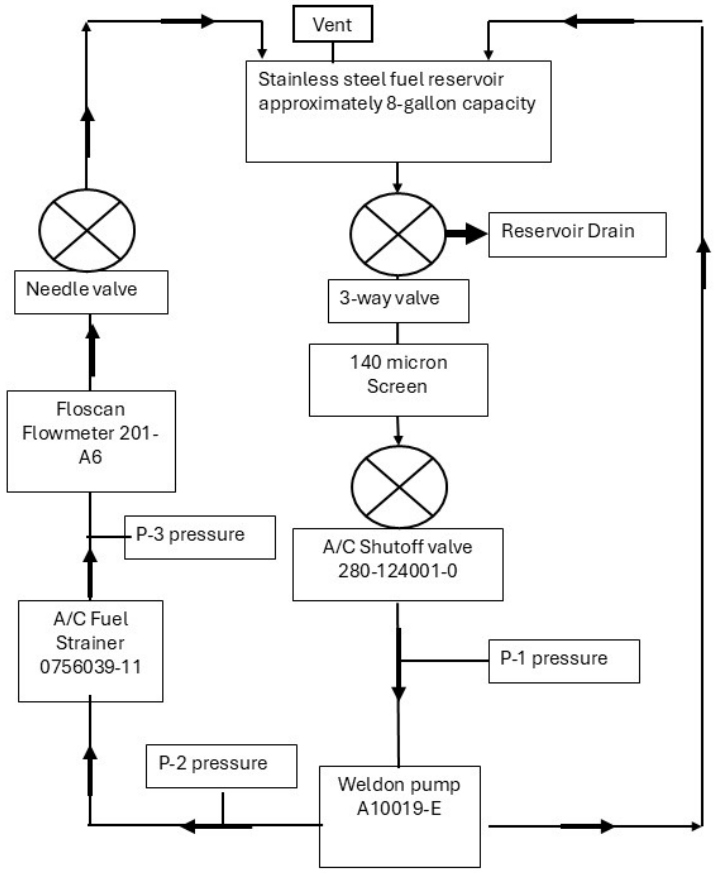
4) Piper / Light GA Loop



- All pressure lines to needle valve: Braided Stratoflex 124
- All lines from needle valve to reservoir chain of MIL-H-6000, Stratoflex 111, and Stratoflex 130

Piper/light GA Loop as built schematic

5) Enstrom Loop

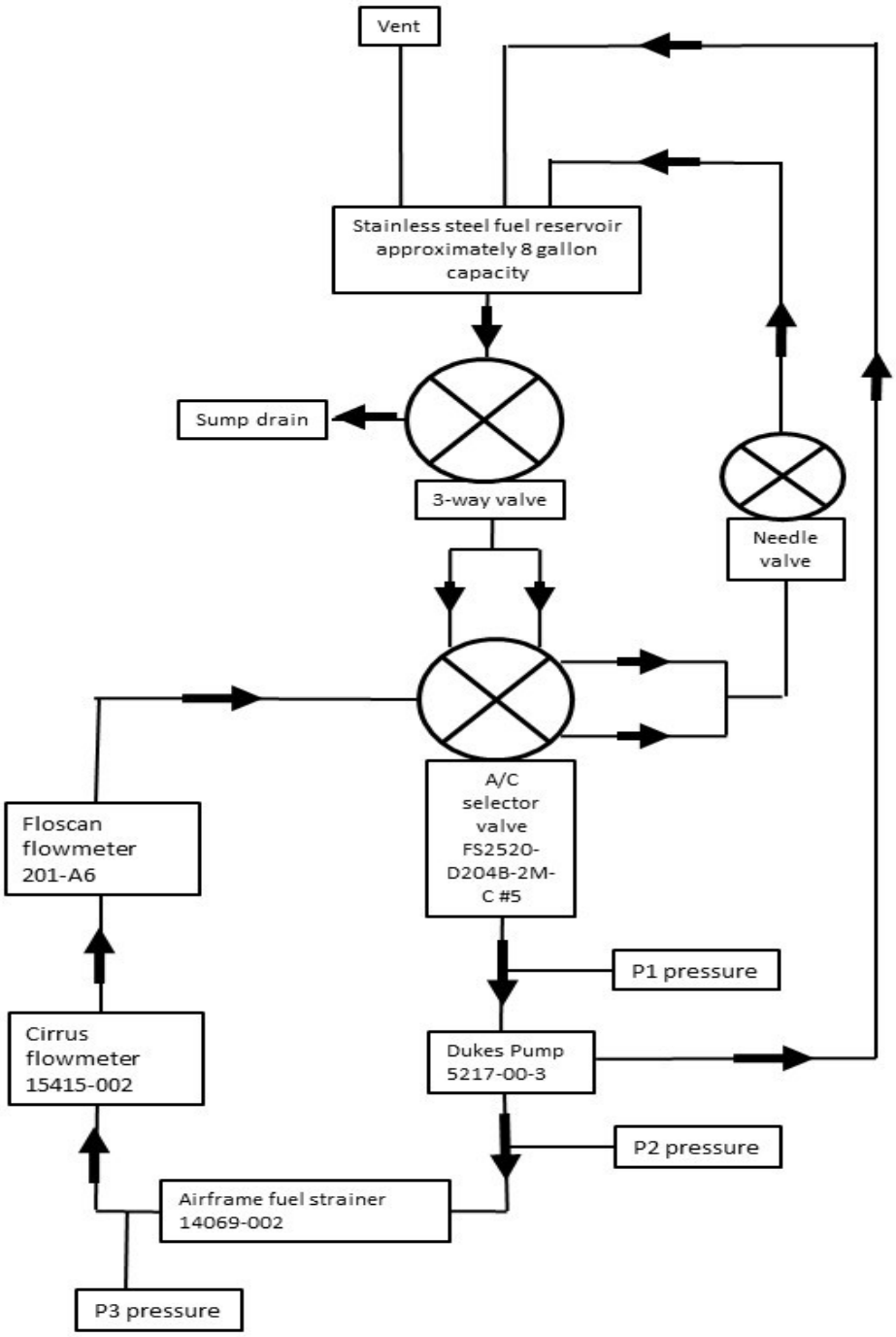


Fuel Strainer 0756039-11

- All pressure lines to needle valve and bypass line: Braided Stratoflex 124
- All lines from needle valve to reservoir chain of MIL-H-6000, Stratoflex 111, and Stratoflex 130

Enstrom Loop as built schematic

6) Cirrus Loop



All pressure lines to needle valve: braided Stratoflex 124

All lines from needle valve to reservoir were a chain of: Mil-H-6000, Stratoflex 111, and Stratoflex 130.

Bypass line from pump to reservoir: Stratoflex 193

Cirrus loop as built schematic

APPENDIX C
EXAMPLE DATA COLLECTION SHEETS

				TCM Stand at -58 °C								
								Pressure PSI				Fuel Type
Date	Time	Cycle No.	Step No.	Pump Speed (RPM)	Flow (GPH)	Fuel Temp (°C)	Dry N2/Air Pressure	P1	P2	P3	P4	
8/1/2015	8:40 AM	1	1	544	5.0-5.8	-59.7		0.35	10.5	5	5	
	8:51 AM	1	2	2699	21.9-23.0	-59.2		0.2	10.5	6	6	
	8:56 AM	1	3	2147	21.2-22.0	-58.8		0.1	10	6	6	
	10:58 AM	2	1	537	6.2	-59.3		0.3	10	5	5	
	11:08 AM	2	2	2705	28	-59.1		0.1	14	7-9	7-9	
	11:14 AM	2	3	2154	27.7	-58.9		0.1	12	6-9	6-9	
	1:15 PM	3	1	542	0	-58.7		0	8	5	5	worked with needle valve and enrichment setting to get flow after ~1 minute
				542	15.6	-58.7		0.1	11	5	5	
	1:25 PM	3	2	2699	29.2	-58.3		0	15	7-9	7-9	
	1:30 PM	3	3	2148	26.5	-57.9		0	13	6-8	6-8	
	3:33 PM	3	3	2147	29.5	-58.2		0	14	6-8	6-8	Final reading before shut down

– END OF APPENDICES –