Methods of Analyzing Synthetic Fuels Onboard for Data Collection and Indication

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Introduction

Background

- Boeing is committed to sustainable aviation fuel (SAF) compatible aircraft by 2030
- In operation both traditional petroleum fuels and SAF will be used and mixed on aircraft
- Petroleum fuels and SAF have different mass and energy densities which must be known for safe operation
- Measurement of density, dielectric constant, fuel level, and hydrocarbon composition are needed
- No sparking hazards are allowed in the tank

Current State

- Currently all above properties are measured except composition
- Newly developed fiber optic methods exist to measure dielectric constant but are not flight proven
- Laboratory instruments exist to determine fuel composition, but are not designed for in flight use

Goals

- Identify and rank techniques to determine of density, dielectric constant, fuel level, and hydrocarbon composition of traditional and SAF blends in an aircraft
- [Stretch goal] Design a test rig to determine the validity of the proposed design

List of Measuring Methods

Measuring methods considered from literature review

Height Measuring
Multi-layer Wireless Sensor
4 Layer Coaxial Cable
Fiber Optic Sensor
Density Measuring
Refractive Index Sensor with 1/3 Rule
Gamma Ray, Ray Attenuation
Hydrostatic pressure
Dielectric Constant Measuring
Refractive Index Sensor
Calculate from density through 1/3 rule
Capacitive sensor
Composition Analysis
FTIR Spectroscopy
Quartz Crystal Microbalance
Mass Spectroscopy
“2D” Gas Chromatograph
Dielectric Spectroscopy

Concept Selection

- A literature review was performed to identify potential methods for fuel level, density, dielectric constant, and hydrocarbon composition.
- Each method was given a score of 1-7 for every criteria seen on the right, which was then multiplied by the scaling factor listed in the right column to give a final rating. An example of this scoring evaluation can be seen below for the use of fiber optic sensing for measuring fuel level:
- Measuring methods with the highest score were selected for the initial design
- After we combined the methods together, we noticed that some compatibility between each methods is important
    - Individual method might have a lower score but together as a whole can be a more cohesive system
- We also found that methods initially given lower scores could be modified to rank higher. For example, the GC x GC system can be stripped down from a laboratory configuration to a lightweight on aircraft configuration, improving the score.

CONCEPT SELECTION MATRIX

Criteria	Scaling Factor
Safety	1
Accuracy/ Precision	0.95
Physical Implementation	0.95
Weight	0.95
Material Costs	0.8
Durability/ Maintenance	0.8
Sustainability/ Ethics	0.75
Schedule	0.5

Example Score Evaluation for Fiber Optic Sensor

	Safety	Accuracy/ Precision	Physical Implementation	Weight	Material Costs	Durability/ Maintenance	Sustainability / Ethics	Schedule
Adjusted Score	7	5.7	5.7	5.7	4	4	3	3

Adjusted Score Total: 38.1/46.9

Methods that were selected for preliminary design:

Height
- **Fiber optic sensor** used in tandem with refractive index sensors placed at the top and bottom of the tank for measuring height

Density
- Using the **refractive index sensor**, fuel density can be determined using the one third rule (see right)
- For added redundancy, a **closed loop manometer** can also be added to the walls of the tank to determine density using **hydrostatic pressure**

Dielectric Constant
- From the fuel's measured **refractive index**, a **correlation** can be used to determine dielectric constant

Hydrocarbon Composition
- A **stripped two-dimensional gas chromatography** located outside the tank can be used to measure the fuel's composition with a polar and nonpolar column in series
- Since it is stripped, only **mandatory components** present to reduce weight and improve implementation feasibility

Key Takeaways

- A concept selection matrix is a highly effective way to narrow down options when so many factors need to be accounted for
- Systems level thinking is key to creating an effective means of collecting all needed data
- More testing of the preliminary design would help future teams determine its effectiveness and areas for improvement, specifically with the fiber optics and hydrostatic pressure portions
- While our experiments were unsuccessful, we learned a lot about systems manufacturing and the strength of the sensors needed for future capstone groups (failing forward for future success)

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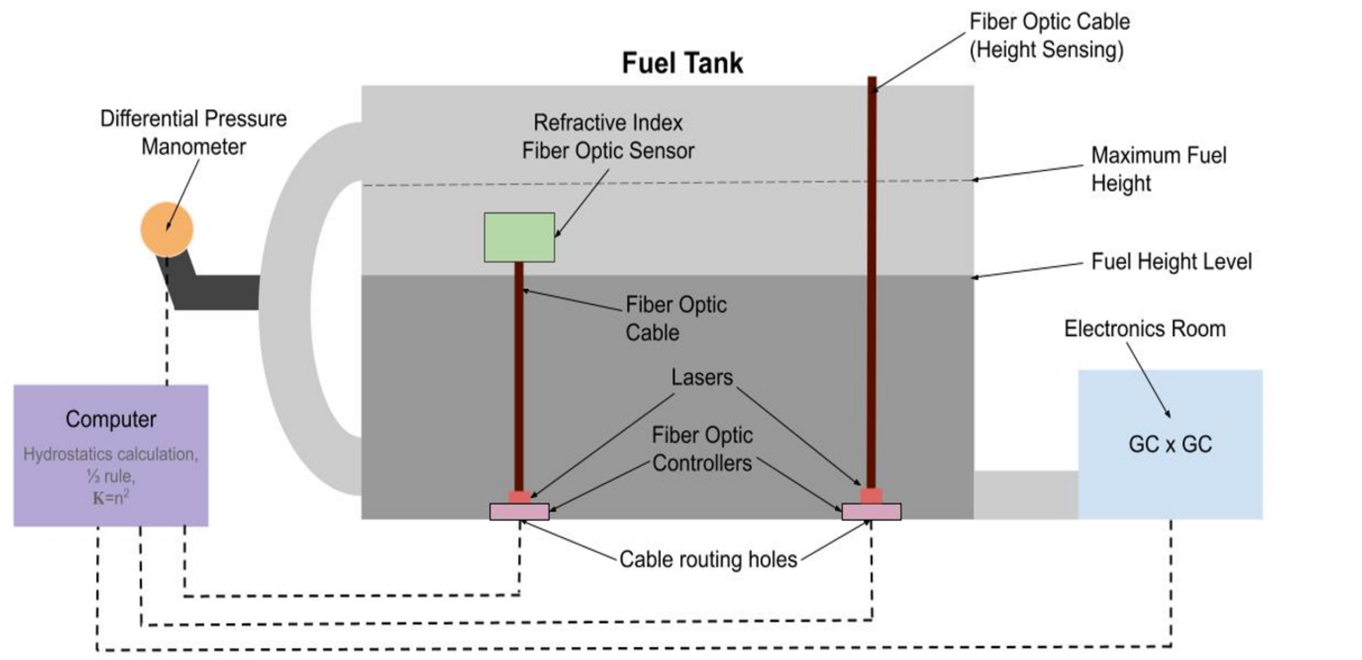
Preliminary Design



Fiber Optic Sensors:
- Low power laser light sent through fiber optic cables interacts with fuel to provide information.
- **Height sensor** determines fuel level through the maximum wavelength reflected through a multi-mode cable, which is determined by the length of the fluid-cable interface.
- **Refractive index sensor** uses the reduced intensity of light due to a bend in the cable exposed to the fluid which lets some light through to determine refractive index

One third rule:
- **Density (ρ)** can be calculated with **refractive index (n)** obtained from the sensor

$$\rho = 3\left(\frac{n^2-1}{n^2+2}\right)$$

- Only applies to nonpolar hydrocarbons but is resilient to changes in pressure, temperature, and composition under flight condition.

Hydrostatic Pressure:
- **Density (ρ)** can also be calculated with the **pressure difference** between headspace and bottom of fuel **(dP)**, along with **height of fuel (h)** and **gravity constant (g)**

$$\rho = \frac{dP}{gh}$$

Dielectric constant (κ) from refractive index (n):
- **Density (ρ)** can be also be calculated with **refractive index (n)** obtained from the sensor

$$\kappa = n^2$$

Two-dimensional gas chromatography (GC x GC):
- Gas chromatography **separates** and measures **composition** of chemical compounds in a mixture of gaseous or liquid sample
- **Stripped machine** can be put in an electronics room and left in a withhold pipe to prevent ignition risks
- Will utilize a **polar** and a **nonpolar column** to analyze individual hydrocarbon and hetero-atomic compounds after vaporizing samples
- Composition data will be used to estimate fuel emissions and energy density