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BOARD # 14: Aircraft Misfuelling: A Case Study Using Bayesian Probability Risk Assessment

Jiahao Yu, Purdue University

Jiahao "Hal" Yu is a Ph.D. student at Purdue University WL in Aviation Technology and Management with research interests spanning various aviation-related projects. He is concurrently pursuing Graduate Certificates in Aviation Financial Management and Applied Statistics while completing his Ph.D.

Prof. Mary E. Johnson Ph.D., Purdue University at West Lafayette (PPI)

Mary E. Johnson is a Professor and Associate Head for Graduate Studies and Research in the School of Aviation and Transportation Technology (SATT) in the Purdue Polytechnic Institute at Purdue University in West Lafayette, Indiana. She earned her BS, MS and PhD in Industrial Engineering from the University of Texas at Arlington

Dr. John H. Mott, Purdue University at West Lafayette (PPI)

John H. Mott is a Professor in the School of Aviation and Transportation Technology at Purdue University. Dr. Mott serves as the Director of the Advanced Aviation Analytics Center of Research Excellence (A3IR-CORE) at Purdue. He holds multiple FAA pilot and instructor certificates. His research is focused on the aggregation and analysis of distributed transportation data using stochastic modeling techniques and the development of related tools to facilitate improvements to system safety and efficiency.

Aircraft Misfuelling: a Case Study Using Bayesian Probability Risk Assessment

Introduction

A statistics course or the application of statistical methods is a fundamental component of engineering and technology education, though it can be challenging for many students. This paper highlights the applicability of statistics in understanding and solving problems in aviation and aerospace education. While many programs rely on descriptive statistics, which assume prior knowledge of the underlying probability distribution of observed data, Bayesian statistics provides a framework for updating beliefs by incorporating both observed data and prior knowledge. One effective way to engage students in statistical methods is by using examples relevant to their technical discipline. This paper presents a contemporary example from the aerospace and aviation fields to illustrate the application of Bayesian statistics.

Additional aviation fuel types are being developed to reduce environmental impacts. However, introducing new fuels into existing fuel infrastructure may also introduce potential complications and operational risks that line service technicians and pilots overlook from time to time - misfuelling. Misfuelling or delivering the wrong type of fuel to an aircraft may lead to severe economic losses and catastrophic safety risks if not detected before fueling or aircraft departure. Misfuelling usually occurs in the General Aviation (GA) sector, where smaller aircraft may use either jet fuel or Aviation Gasoline (Avgas), which cannot be identified by the overall appearance of the aircraft [1]. The example in this study investigates the occurrence of past misfuelling events using Bayesian inference, discusses current preventative practices, including placarding, education, etc., and emphasizes the importance of robust education after the integration of new fuels. Past accidents and incidents are grouped into three-year intervals. Bayesian inference is used to generate the probability density distribution of past misfuelling events. When new data on misfuelling becomes available as SAF becomes more widely adopted, the current probability model can be used to gain new insights. This type of example may also inspire students in aerospace and aviation programs to learn more about aviation carbon emissions and the use of non-parametric statistics and Bayesian techniques.

Background

Pedagogy of Statistics for Non-statisticians

While many statistics course sequences begin with basic probability, sample sizes, descriptive statistics, confidence intervals, and hypothesis tests, these topics fundamentally rely on underlying probability distributions. A study analyzing responses from 183 participants at the University of Colorado at Boulder identified 30 threshold concepts for introductory statistics courses, as recognized by both students and instructors [2]. However, Bayesian inference was not among these identified concepts. While the study acknowledged students' difficulty in understanding the basic principles of probability, researchers did not further investigate Bayesian inference [2]. Bayesian inference, however, can provide more logical and intuitive interpretations, allowing students to make direct probability statements [3]. Bayesian methods produce probability distributions, whereas the traditional frequentist approach relies on confidence intervals and does not assign probabilities to parameters.

Teaching Bayesian methods, however, presents certain challenges, ranging from pedagogical approaches to content selection, especially for students who are not majoring in mathematics or statistics [3]. Ferrari proposed a four-step modeling approach to help students shift their mindset from a non-Bayesian to a Bayesian paradigm [3], which is introduced in the Methods section of this paper. One key advantage of this four-step approach is that it provides a logical and comprehensive view of the process, rather than encouraging students to mechanically plug data into different models and distributions [3].

While advocating for the inclusion of Bayesian statistics in intermediate and advanced statistics courses, Utts and Johnson successfully conducted a one-week workshop on using Bayesian methods for diagnostic testing in veterinary epidemiology [4]. The key pedagogical aspects of the course included: 1. Introducing fundamental probability theory through diagrams and graphical displays. 2. Developing a conceptual understanding of the likelihood function, as well as prior and posterior distributions. 3. Emphasizing data modeling relevant to students' technical disciplines. 4. Connecting scientific knowledge with model parameters. 5. Providing hands-on experience throughout the course [4]. There are many other successful cases of teaching Bayesian statistics to medical students with limited statistical backgrounds, as well as business and marketing students who may be resistant to likelihood-based methods due to long-term exposure to econometrics [5, 6]. In both cases, the results have been promising, demonstrating significant benefits [5, 6].

Aviation Fuel

This section provides a holistic view of aviation fuels and addresses issues related to aircraft misfuelling. Three primary types of aviation fuels, including jet fuel, Avgas, and biofuel, are discussed in this section, along with three key topics on aircraft misfuelling: the risks associated with incorrect fuel and fuel additive, the role of placards and nozzles, and the importance of misfuelling prevention education. These topics provide background information for educators to develop relevant examples illustrating the use of Bayesian statistics in undergraduate or graduate courses for students with algebraic proficiency and basic knowledge of descriptive statistics.

Jet Fuel is a kerosene-based fuel predominantly used in the aviation industry to power turbine engines and the new generation of compression piston diesel-powered aircraft [7]. Jet A and Jet A-1 are the primary types of commercial jet fuel [8]. Jet A is mainly used in the United States, whereas Jet A-1 is commonly used in other regions worldwide [8]. Jet A and Jet A-1 differ in their freezing points, with Jet A freezing at -40 °C and Jet A freezing at -47 °C [9]. Jet fuel is a complex mixture of heavier hydrocarbon compounds, primarily composed of hydrocarbons with carbon chain lengths ranging from 8 to 16 [9]. Jet fuel has high chemical stability, making it easy to store and less likely to evaporate or degrade over time. Jet Fuel adheres to the ASTM D1655, Standard Specification for Aviation Turbine Fuels, which mandates a flash point requirement of 38 °C minimum among other requirements identified in the standard [9].

As indicated by its name, Avgas is a gasoline-based fuel primarily for spark-ignition piston-engine aircraft. Avgas adheres to the ASTM D910, Standard Specification for Aviation Gasolines, which defines lead-containing aviation gasolines [10]. Conventional Avgas has tetra-ethyl lead added to the gasoline during processing, and the lead is essential for the safety of flight operations for certain aircraft [9]. Jet fuel is a kerosenic fuel; Avgas is a gasoline fuel.

Unleaded Avgas is the focus of the FAA launched the Eliminate Aviation Gasoline Lead Emissions (EAGLE) initiative. The EAGLE initiative aims to eliminate the use of leaded aviation fuel by the end of 2030 [11]. While there are significant environmental benefits, eliminating the use of leaded Avgas faces numerous challenges and introduces greater uncertainty to the fueling process, especially during the transition phase. The FAA has approved two unleaded Avgas: Swift's fuel UL94 and General Aviation Modifications, Inc.'s fuel G100UL [12]. Swift's fuel has been commercially available for nine years and meets the ASTM International Standard, ASTM D7547, Specification for Hydrocarbon Unleaded Aviation Gasoline [12]. While G100UL holds an FAA Supplemental Type Certificate, it does not have an industry consensus standard specification yet, such as ASTM D910 or ASTM D7547 [12]. As most FBOs do not have the tanking capability to have two or more grades of Avgas, if an FBO switched to Swift's UL94 fuel, then that FBO would not be able to provide Avgas to aircraft that require a 100-octane level Avgas without providing additional storage tanks and refueling equipment [12].

Bio-Avgas is also under development, but its scale remains relatively small due to the limited market for piston engine aircraft interested in biofuels, along with other challenges.

Aircraft Misfuelling

Aircraft misfuelling may occur at any of the interfaces along the supply chain after the fuel is refined. Figure 1 highlights the major processes in the life cycles of aviation fuels [13].

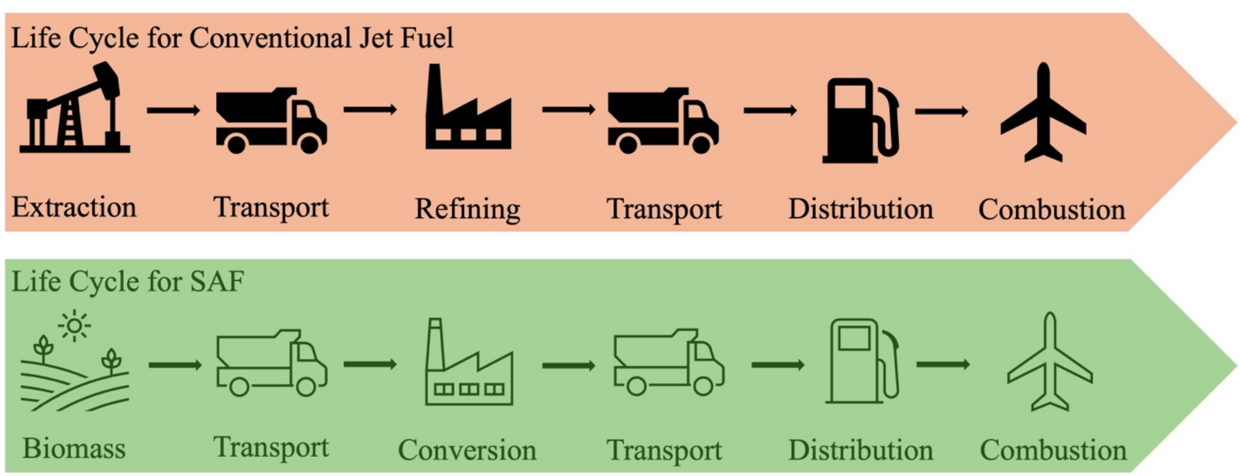

Figure 1. Life Cycles for Conventional Jet Fuel and SAF, adapted from [13]

Errors may occur where fuel is mislabeled at the refinery, at the transportation points, at the distribution points, or at the point the fuel is dispensed to the aircraft. Wherever the fuel is transferred, there is a point of potential failure. In the misfuelling case, either the fuel tank contains fuel that does not match the label on the tank, or the incorrect fuel is delivered to the aircraft fuel tanks.

On October 5, 2019, a pilot operating a Piper Aerostar 602P, a reciprocating engine-powered aircraft, exceeded the critical angle of attack after experiencing a dual engine power loss caused by the addition of wrong fuel. The aircraft subsequently crashed into a soybean field [14]. According to the statement of the line service technician, the airplane resembled a jet aircraft. He asked the pilot if he wanted jet fuel and received an affirmative response [14]. Due to the severe consequences of using the wrong fuel in an engine, airports use different fueling nozzles for Jet-A fuel and Aviation Gasoline (Avgas). The line service technician on duty managed to fill the tank using the Jet-A fuel nozzle by tilting it 90 degrees over the wing fuel tank filler neck and approximately 45 degrees over the fuselage filler necks [14].

This tragic fatal aircraft crash in Kokomo, Indiana brought public attention back to the rare yet potentially catastrophic consequences of misfuelling if not identified before fueling or aircraft departure. Misfuelling usually occurs in the General Aviation (GA) sector, where smaller aircraft may use either jet fuel or Avgas that cannot be identified by the overall appearance of the aircraft. The fuel type is known and knowable to the pilot because the Pilot Operating Handbook identifies the specified fuel for an aircraft. In addition, aircraft regulations require placards identifying the approved fuel type to be displayed on aircraft, yet the mistake of misfuelling still occurs.

While the Pilot in Command is responsible for ensuring the safety of the aircraft and its operation, there may be the stresses of time pressures and physical pressures, along with complacency associated with a basic, routine task such as refueling. Jet fuel is a kerosene-based fuel primarily used in turbine engines. When introduced into reciprocating engines, it may allow the aircraft to start, run, and power long enough to become airborne, but the engine will likely fail shortly after takeoff [7].

The Risks Associated with Incorrect Fuel and Fuel Additive

Misfuelling is delivering the wrong type of fuel to an aircraft with an engine that has different fuel requirements [1]. For piston engine aircraft, misfuelling includes the use of jet fuel in spark ignition piston engine aircraft, Avgas in compression ignition piston engine aircraft, and Avgas with the incorrect octane level in the spark ignition piston engine aircraft [1]. For jet turbine engine aircraft, misfuelling includes the use of Avgas in turbine engine aircraft [1]. Fueling an aircraft with the wrong fuel can have serious consequences, including total engine failure due to knock damage if jet fuel is used in spark ignition piston engine aircraft, ignition failure if Avgas is used in compression ignition piston engine aircraft (which ideally use diesel but can usually operate on jet fuel), vapor lock and engine failure due to fuel starvation if Avgas is used in turbine jet engine aircraft, and potential engine failure or power loss if Avgas with the incorrect octane level Avgas is used in spark ignition piston engine [1]. Table 1 shows the consequences of adding jet fuel and Avgas to compression piston engine, spark piston engine, and turbine jet engine, compiled from information in [1].

Table 1. Matching Engine Types with Fuel Types (Compiled from information in [1]).

Engine Type	Fuel Type	
	Jet A	Avgas
Compression Ignition Piston Engine	Diesel used in older models. Jet A is okay for certain models.	Ignition failure
Spark Ignition Piston Engine	Total engine failure due to knock damage	Right, but incorrect octane level Avgas will cause potential engine failure and power loss
Turbine Jet Engine	Right	Vapor lock and engine failure due to fuel starvation

Especially when jet fuel is used in spark ignition piston engine, the jet fuel causes abnormal combustion. Engine knock, also known as spark knock, is the noise produced by irregular combustion [9]. Extended knocking can lead to power loss and engine failure due to overheating of engine components and knock-induced surface ignition [9]. The damage may have disastrous consequences, as adding jet fuel to the avgas in the fuel tanks would allow a spark ignition aircraft to start, run, and remain powered long enough to become airborne, but the engine is likely to fail shortly after takeoff [7]. If Avgas gets contaminated by jet fuel, the octane level of the fuel will also decrease. When there was a 5% Jet-A contamination in Avgas, the octane value decreased by 4.7, while a loss of 2 to 3 in octane value could potentially use up the design safety margin [15].

In the Energy Institute (EI) recommended Practice 1597, procedures for overwing fueling to ensure delivery of the correct fuel grade to an aircraft, five common causes were identified: lack of confirmation between the fuel customer and supplier, lack of clear identification of the appropriate fuel grade on the aircraft, lack of clear identification on the refueling equipment, inadequate training and human errors, and similarity between aircraft requiring different types of fuel [1]. FAA's Dirty Dozen may also be used to identify potential human error sources rooted in communication failures, complacency or overconfidence, and lack of knowledge [16].

Another, less common but serious threat is the use of the wrong additive. On April 23, 2023, the fueler accidentally added Diesel Exhaust Fluid (DEF) to the Fuel System Icing Inhibitor (FSII) reservoir, which was then mixed with Jet A and used to fuel the incident aircraft [16]. The aircraft nearly lost power on both engines and made a dead-stick landing, coming to a stop approximately 650 feet from the runway end [17].

Placards and Nozzles

While required by 14 CFR 25, placards may be in place; however, there were occurrences where placards were complied with by pilots and/or refuelers, at least in part due to human errors. In

Title 14 Code of Federal Regulations, Part 25.1557 Miscellaneous Markings and Placards, aircraft fuel openings must show the minimal fuel grade for piston engine aircraft and approved fuel types [18]. The provision of these markings and placards is the responsibility of the original equipment manufacturer (OEM), while the aircraft owner/operator is responsible for their maintenance [1].

The aviation industry has been addressing misfuelling events since its rise decades ago; different fuel nozzles have different spouts to reduce misfuelling events. Jet fuel nozzles use a wide nozzle spout with a major axis of at least 67 mm or 2.66in, while Avgas nozzles use a small diameter spout that is 50 mm or 1.97 in [1]. This created a physical barrier to prevent misfuelling events. Even with these spouts, misfuelling still occurs.

Misfuelling Prevention Education

A wide range of resources is available for operators and FBOs to educate line personnel. All personnel involved in aircraft fueling should be trained on the importance of fueling the aircraft with the correct fuel and addictive [1]. The National Air Transportation Association (NATA) provides various resources for misfuelling education and certification, free of charge. These resources can serve as a starting point for FBOs or operators to provide initial training for new hires and recurrent training for seasoned employees. To train professionals in raising awareness, a combination of online classes, in-person workshops, and other introductory courses can be beneficial to increase people's interest and awareness [19]. By addressing the lack of knowledge on a continual basis, then other mitigations are necessary to address communication failures and complacency.

Methodology

Ferrari proposed a four-step modeling approach in teaching Bayesian statistics [3]:

1. Choose the data model.
2. Choose the prior distribution.
3. Derive the posterior distribution.
4. Compute the key posterior estimates.

The four steps align with the example used in this study, which applies Bayesian methods to technical aviation and aerospace disciplines. In this study, Bayesian inference is used to analyze NTSB final reports for misfuelling events reported from 1989 to 2024. These reports are available on NTSB Case Analysis and Reporting Online (CAROL) [20] and can be assessed using the CAROL query with the NTSB accident number. This section introduces the Poisson distribution, key assumptions, Jeffreys' prior, the updating rule for the posterior, and hypothesis testing.

Poisson Distribution

The binomial distribution is frequently applied when discrete events in an experiment consisting of independent trials have only two possible outcomes: failure or success. In a binomial distribution Bin (n, π), the discrete probability mass function for the random variable X (k = 0, 1, 2, ..., n) given probability π [21] is

$$P(X = k|\pi) = \binom{n}{k}\pi^k(1-\pi)^{n-k} \quad (1)$$

where π is the probability of event occurrence, n is the number of independent trials, and k are the values taken on by the random variable X. The variable n is typically known. However, as the number of experiments becomes very large, and the probability of the event happening is small, the binomial distribution approaches a limiting case, which can be approximated by the Poisson distribution [21]. The Poisson distribution models the count of rare events occurring within a specific time period or spatial area. Considering each flight operation as a trial where the probability of a misfuelling event is π, the number of flight operations is large, and the probability of aircraft misfuelling is small, let the Poisson parameter $\mu = n\pi$. Then the probability mass function for the random variable X (k = 0, 1, 2, …) given μ [21] is

$$P(X = k|\mu) = \frac{\mu^k e^{-\mu}}{k!} \quad (2)$$

where π is the probability of event occurrence, n is the number of independent trials, and k are the values taken on by the random variable X.

When using the Poisson distribution, it is assumed that the data adheres to the characteristics of this distribution, which is introduced in the next section. The Poisson distribution has a unique property where both the mean and variance are equal to μ [21]:

$$E[X|\mu] = \mu \quad (3)$$

$$Var[X|\mu] = \mu \quad (4)$$

Assumptions

The assumptions for this study are as follows:

1. The probability of misfuelling is constant for each flight operation;
2. Each fueling operation is considered independent of the others;
3. For each fueling operation, misfuelling can only either occur or not occur; and
4. The possible values for k range from 0 to n.

The goal of the study is to estimate the value of the Poisson parameter μ, which represents the average number of annual misfuelling events, from the historical data using Bayesian inference.

Jeffreys' Prior

Since no prior information is available about the occurrence pattern of misfuelling events, the only understanding we have is that data is scarce, and such events occur infrequently. Jeffreys' prior is suitable in this case, as it assigns more importance to smaller values of the rate parameter μ, providing a neutral starting point. The Jeffreys' prior for the Poisson distribution [21] is

$$P(\mu) \propto \frac{1}{\sqrt{\mu}} \text{ for } \mu > 0 \tag{5}$$

where μ is as previously defined.

Equation (5) tends to have large values when μ is close to 0, which aligns with our expectations for misfuelling events. On the other hand, the gamma distribution is the conjugate prior to the Poisson distribution, meaning it offers significant advantages when updating the distribution as data becomes available [21]. Jeffreys' prior for the Poisson distribution with parameter μ has the form of a gamma (0.5, 0) prior where the rate parameter v is close to 0 [21]. A gamma (r, v) distribution is used for continuous variables that have nonnegative values; the probability density function for gamma (r, v) [21] has the form

$$P(x; r, v) = c * x^{r-1} e^{-vx} \text{ for } 0 \leq x < \infty \tag{6}$$

where c is a normalization constant, r is the shape parameter, and v is the rate parameter.

Updating Rule

The probability density function of the gamma (r, v) conjugate prior for the Poisson (μ) [21] is

$$P(\mu; r, v) = \frac{v^r \mu^{r-1} e^{-v\mu}}{\Gamma(r)} \tag{7}$$

where $\Gamma(r)$ is the gamma function.

The Bayesian posterior distribution, then, is proportional to the product of the prior and the likelihood function. The likelihood is given by the probability density function of the Poisson distribution [21]:

$$P(\mu|x) = \frac{v^r \mu^{r-1} e^{-v\mu}}{\Gamma(r)} * \frac{\mu^k e^{-\mu}}{k!} \tag{8}$$

$$P(\mu|x) \propto \mu^{r-1+k} e^{-(v+1)\mu} \tag{9}$$

Noting the relationship between the prior and posterior distributions (obtained by careful selection of the prior as conjugate to the Poisson family), one may develop a simple rule to derive the posterior from the prior, based on additional data. The updated posterior distribution gamma (r', v') is found to be [21]:

$$r' = r + k \tag{10}$$

$$v' = v + 1 \tag{11}$$

where r is the prior shape factor, v is the prior rate factor, r' is the posterior shape factor and v' is the posterior rate factor.

This study used RStudio® software from Posit™ to find the posterior distribution. Note that v → 0 is a limiting case for the gamma distribution; because the software will not accept a value of 0 for v, an arbitrarily small value was selected (0.5). The following R functions are available in the gamma distribution functions library within the RStudio® software [22]:

```
dgamma(x, shape, rate, log = FALSE)
pgamma(q, shape, rate, lower.tail = TRUE, log.p = FALSE)
qgamma(p, shape, rate, lower.tail = TRUE, log.p = FALSE)
```

The dgamma function provides the probability density, the pgamma function provides the distribution function, and the qgamma function provides the quantile function.

Results

Data Display

Misfuelling events from 1989 to 2024 from the NTSB CAROL query are shown in the dot plot in Figure 2. Misfuelling events occur 0 to 3 times each year, where each dot represents one misfuelling event.

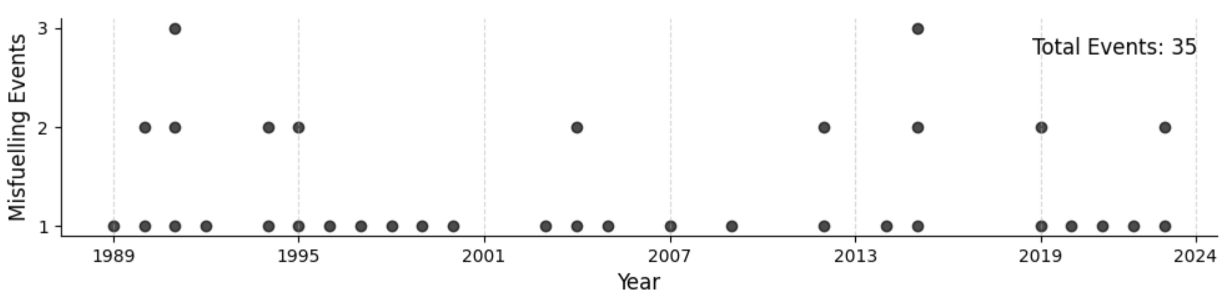

Figure 2. Dot Plot for Misfuelling Events 1989 – 2024 from NTSB CAROL Database (Total: 35).

The 35 misfuelling events are categorized according to the five common causes identified by EI 1587 as shown in Figure 3 [1]; some of these events involve multiple causes in a single accident.

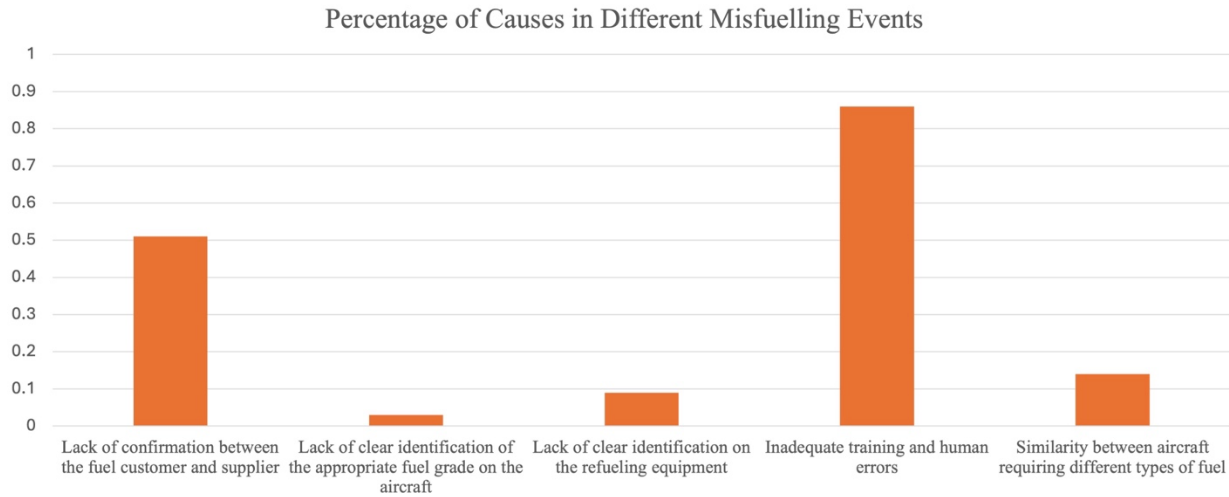

Figure 3. Percentage of Causes in Different Misfuelling Events.

Out of 35 documented misfuelling events, only one event in 2005 specifically mentioned that the fueling ports were not placarded with the required statement indicating that only Avgas should be used [23]. In seven events, the investigator explicitly mentioned that placards were present, but the line service technicians either did not notice them or failed to pay attention. There were 12 events in which the FBO did not equip the Jet A fuel truck with the proper nozzle. Inadequate training and human errors (Cause 4) were identified in 30 out of these events. Notably, 25 of these events involved either jet fuel being added to aircraft that required Avgas.

Posterior Distribution

Table 2 shows descriptive statistics of the Bayesian posterior computed from the misfuelling event data. The equal tail area 95% Bayesian credible interval for μ is [1.98, 3.85]. A credible interval is not to be construed to be the same as a confidence interval typically used in frequentist inference. Bayesian credible intervals are analogous to prediction intervals in frequentist inference.

Table 2. Descriptive Statistics of Bayesian Posterior Distribution for Misfuelling Events.

Bayesian Posterior Distribution	Mean	Median	Mode	St. Dev.	IQR
Gamma (35.5, 12.5) (function (6))	2.84	2.81	2.76	0.48	0.64

The posterior distribution for μ is shown in Figure 4.

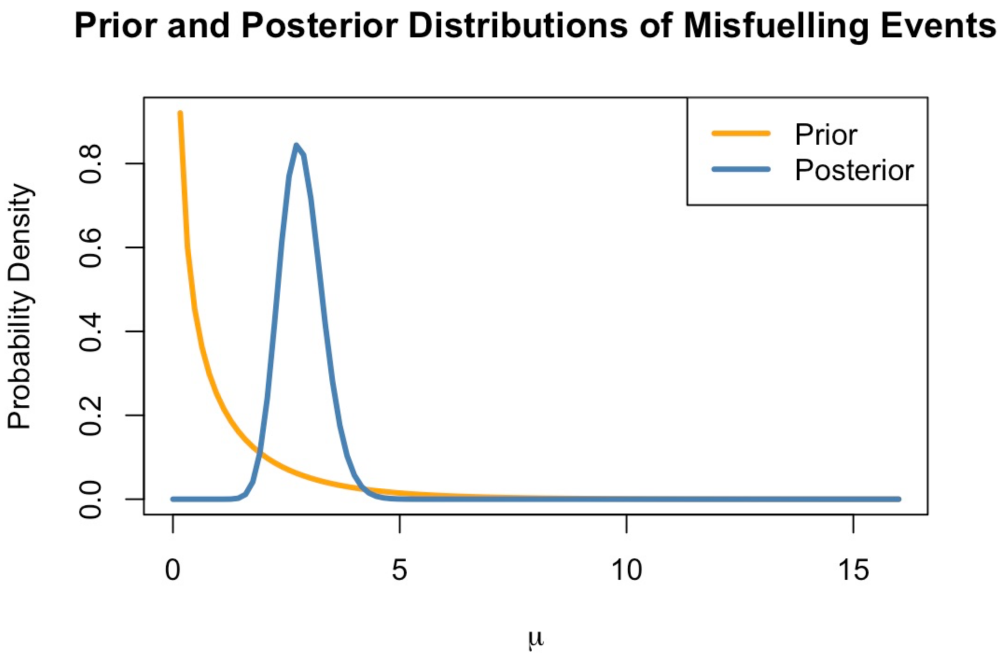

Figure 4. Posterior Distribution of μ.

Hypotheses Testing

Null hypothesis testing is easily conducted once the credible interval is computed. One-sided hypotheses require integration of the posterior up to the hypothesized value, which is easily accomplished in R. Two-sided hypotheses require nothing other than comparison with the credible interval; if the null lies within the credible interval, it may not be rejected.

Discussion

Summary of Findings

Bayesian inference is a robust, yet underutilized, framework providing capabilities for rich statistical analysis. The example provided here is no doubt of interest to aeronautical engineering and aviation students because it yields insights into the occurrence of the rare yet consequential event of aircraft misfuelling. The Bayesian credible interval computed for the 35-year record of misfuelling events [1.98, 3.85] indicates a 95% probability that the rate of misfuelling occurrences lies between 1.98 and 3.85 per year. An excellent discussion with students is the difference between the Bayesian credible interval and frequentist confidence intervals. The significant advantage of the Bayesian approach is that the posterior distribution completely characterizes the process based on observed data and may be used for direct computation of any statistic of interest. The frequentist confidence interval, of course, does not provide a probability that the parameter of interest lies within a particular confidence interval. The only way such a probability can be obtained is from computation of all possible confidence intervals, a task which is generally difficult if not impossible.

An in-class discussion or out-of-class assignment may be the connection of this type of analysis to the characterization of safety and risks. In this example, most of the events (30 out of 35 misfuelling events) were attributed to the same cause of inadequate training and human errors, highlighting the need for greater investment in misfuelling prevention and education. Relying solely on just the placards (1 out of 35 misfuelling events) or fuel nozzles (12 out of 35) is insufficient. As the integration of SAF soon and the transition of Avgas to unleaded by 2030, the complexity of fueling operations will potentially increase. The importance of avoiding misfuelling has been emphasized throughout the paper. Refueling agents, operators, and organizations must recognize the challenges and allocate more resources to misfuelling prevention and education to minimize the associated risks.

Strengths and Limitations

The data for this research is sourced from the NTSB CAROL database [20]. Therefore, misfuelling events that are not reported by NTSB are not included. Additionally, some misfuelling reports in the NTSB database may not have been included in this study due to the absence of specific coding for misfuelling incidents or accidents. Other potential sources, such as the FAA's Service Difficulty Reports (SDRs) and NASA's Aviation Safety Reporting System (ASRS), were not used due to the unreliable nature of anonymous and /or voluntary reports. There may be misfuelling events beyond those captured in the NTSB database.

All of the misfuelling events used in this research are from NTSB *final* reports, indicating that there was a level of damage to people or property that required an NTSB investigator to file the report.

Future Research

For future research, as more airports begin to adopt SAF for Jet-A or other aviation fuels, the question of detectability of the misfuelling event before the aircraft departs or before the misfuelling occurs arises. While pilots may test the fuel in the fuel tank after every refueling by drawing a sample from each fuel drain or sump, misfuelling is not always detectable due to lighting conditions or due to the amount of mixing of fuels in the fuel tanks or other conditions. The introduction of new fuels into existing fuel infrastructure suggests potential complications and presents operational risks, as well. When data becomes available after the integration of new fuels into the airport fueling system, the newer data can be used to update this research. The posterior distribution computed in this study, gamma (35.5,12.5), can serve as the prior for future research studies. The unique feature of using Bayesian statistics is that prior knowledge may be directly utilized in the analysis of all future information.

Implications of Teaching Bayesian Methods Using Examples from Technical Disciplines

Most non-statistics major students take only a few statistics courses as part of their program requirements, leaving them with little exposure to the significant benefits and logical reasoning behind Bayesian statistics [24]. Bayesian statistics may seem intimidating to students and even faculty members unfamiliar with this alternative approach to statistical inference. However, it becomes much more accessible once students grasp the logic of the incremental updating process used in Bayesian statistics. By incorporating technical examples, such as the one presented in this paper, Bayesian methods can become more engaging and may enhance students' learning experiences. Interesting future research may involve the development of other examples using available aerospace and aviation data to conduct analyses and to compare the assumptions, data requirements, and testing requirements for both frequentist and Bayesian statistics.

Conclusion

This research provides an innovative approach to inspire students to explore technical problems using Bayesian inference. The example presented provides greater insight into these techniques using data associated with a potentially dangerous but rare event. This example may also be used to better aid students in understanding the use of Risk Assessment Matrices and Failure Modes and Effects Analysis. Relying solely on procedures does not appear to be sufficient to prevent these misfuelling events. Greater investment is needed in misfuelling prevention, detection, and education to reduce the consequences. More attention must be focused on preventing the severe consequences of misfuelling events rather than waiting for an incident to occur before initiating educational efforts and preventive measures.

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