Flight Phases and Fatality in Aviation

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Introduction

The aviation industry offers many services and conveniences, and over the years, it has made a lot of progress to improve the safety of flying. People fly for various reasons, such as leisure/travel, business, cargo and shipping, aerial observation and research, personal hobbies, etc. Just as other transportation modes, things can go wrong during a flight, and unfortunately, we have seen many catastrophic accidents resulting in the loss of many lives. An aviation accident is usually followed up by a thorough investigation to determine the factors causing the accident and to ensure that lessons are learned to prevent similar occurrences.

This project will use aviation accidents' historical data to focus on the flight phase during which the accidents occurred and the fatalities caused. We will try to address the question: which flight phase is more dangerous? The answer to this question could motivate a more focused study to improve aviation safety, either through some technology advancement, regulation implementation, or modifications in operational practices.

To answer this question using the information available in the dataset, we would first compare the number of accidents across the different flight phases. In each accident, the people on board could either be uninjured, injured (minor to serious injuries) or fatally injured. If an accident has at least one person that is fatally injured, the accident is considered fatal. We will then compare the fatality rate for each accident across the different flight phases. We will use the logistic binomial model to model the fatality proportion in each accident as a function of the flight phase.

Data Overview

The aviation accidents data set we use is accessible from Kaggle website[1], and is originated from the National Transportation Safety Board (NTSB) database. It contains information about aviation accidents, the oldest one being from November 1948. There is only one recorded accident for that year. The latest recorded aviation accident in the data set is dated May 9th, 2020. There is more than 84,000 aviation accidents and incidents in the data set from various countries. According to the NTSB website, an accident is defined as "an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage". On the other hand, an incident is defined as "an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations.."[2] For this project, we will only look at the recorded accidents.

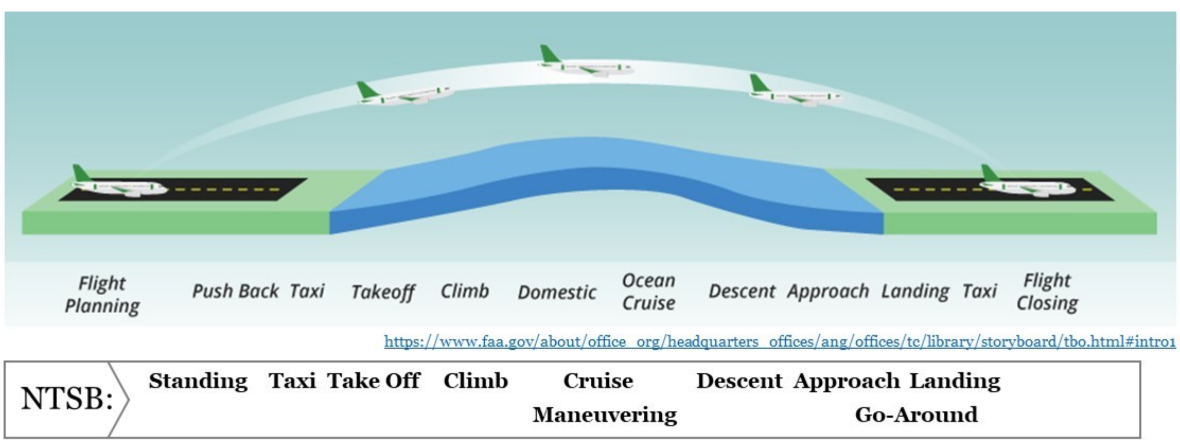
To address our research question, we will focus on the columns for the number of injuries and fatalities and the column indicating the flight phase during which the accident occurred. Below is a preview of the information we use from the data set.

[1] https://www.kaggle.com/khsamaha/aviation-accident-database-synopses
[2] https://www.ntsb.gov/_layouts/ntsb.aviation/AviationQueryHelp.aspx

Table 1: Preview of the NTSB Aviation Accident Data Set

Date	Location	Total Fatal Injuries	Total Serious Injuries	Total Minor Injuries	Total Uninjured	Flight Phase
2020-04-25	East Hampton, NY	0	0	0	3	APPROACH
2020-03-20	Canyon, TX	0	0	0	1	LANDING
2020-01-08	Tehran, Iran	176	0	0	0	TAKEOFF
2019-05-05	Moscow, Russia	41	0	0	39	TAKEOFF
2015-07-22	Tifalmin Village Papua New Guinea, Papua New Guinea	0	0	1	0	MANEUVERING
2012-01-30	Cascade, ID	0	0	0	1	LANDING

There are some missing data in the data set. We exclude any accidents that have incomplete information about the number of people on board and any accidents that do not have information about the flight phase or any with "UNKNOWN" flight phase. The flight phase in this data refers to "the point in the aircraft operation profile in which the event occurred."[3] There are 10 flight phases in the data set: Standing, Taxi, Take Off, Climb, Cruise, Descent, Maneuvering, Approach, Go-Around, and Landing. Explanation of each phase could be found here[4]. The FAA (Federal Aviation Administration) website has an illustration of the different flight phases. The NTSB uses slightly different wordings for the phases, and these are added to the picture to help illustrate the flight phases in the data set.



If an accident involves two aircraft, the original data set would have two rows, one for each aircraft. But the number of injuries and fatalities are duplicated in both rows, so we remove the duplicated record before proceeding to work with the data. This leaves us with 73,514 rows of aviation accidents. Below is the summary of the variables of interest from the data set.

[3]https://www.ntsb.gov/_layouts/ntsb.aviation/AviationDownloadDataDictionary.aspx
[4]https://www.ntsb.gov/investigations/data/Documents/datafiles/PhaseofFlightDefinitions.pdf

```
Total.Fatal.Injuries Total.Serious.Injuries Total.Minor.Injuries
Min.   :  0          Min.   : 0             Min.   :  0
1st Qu.:  0          1st Qu.: 0             1st Qu.:  0
Median :  0          Median : 0             Median :  0
Mean   :  0          Mean   : 0             Mean   :  0
3rd Qu.:  0          3rd Qu.: 0             3rd Qu.:  0
Max.   :265          Max.   :81             Max.   :171

Total.Uninjured Total.Souls.Onboard Broad.Phase.of.Flight
Min.   :  0     Min.   :  1         LANDING    :20096
1st Qu.:  0     1st Qu.:  1         TAKEOFF    :15737
Median :  1     Median :  2         CRUISE     :10620
Mean   :  3     Mean   :  4         MANEUVERING:10235
3rd Qu.:  2     3rd Qu.:  2         APPROACH   : 7731
Max.   :699     Max.   :699         DESCENT    : 2169
                                    (Other)    : 6926
```

The observation unit for "Broad.Phase.of.Flight" is the aviation accident or the number of flights that end up in accidents, whereas the other variables records the number of injuries or individual unit. We see that the number of injured persons is mostly 0, with the nonzero numbers appearing mostly between the third and maximum. This is because most of the flights in the data carry only a few people on board, as seen in the summary for the variable "Total.Souls.Onboard". About 80% of the flights have less than three souls on board. These are usually flights for personal, business, instructional, aerial application, and aerial observation purposes. There are many other aviation accidents that we can not include in this study because there is no known information for the flight phase during which the accident occurs.

Data Visualization

As mentioned earlier, to learn about which flight phase is more dangerous, we first observe and compare the number of accidents during different flight phases. Figure 1 shows the number of accidents during the different flight phases, where the color indicates fatality. Fatal accidents are all accidents that involve at least one fatality.

We can see that landing and take-off have the highest number of accidents. However, most of these accidents are not fatal. The highest numbers of fatal accidents occur during maneuvering, cruise, take-off and approach. The NTSB website describes the maneuvering phase as "low-altitude/aerobatic flight operations". Furthermore it explains that these are usually performed in air shows, training flights, observation work, demonstration, photography work, aerial application, or other similar activity[5].

Another way to see which flight phase is more dangerous is by comparing the number of injuries caused by the accidents that happened during the different flight phases. The data set classifies the injuries into four categories: fatal injuries, serious injuries, minor injuries, and uninjured. Figure 2 shows that maneuvering, cruise, take off, and approach have the highest number of fatalities. We noted earlier that these four phases have the top four number of fatal accidents.

One good thing to point out is that, except for maneuvering, the number of uninjured is greater than the number of fatalities. We see that in most of the flight phases, there is a fair amount of people uninjured. When we compare the number of accidents earlier in Figure 1, we see that the number of fatal accidents in maneuvering is far higher than the other flight phases. However, when we compare the number of fatalities, maneuvering does not differ by much from cruise and take off. Most of the accidents that happen during maneuvering are flights for personal, aerial application, and instructional purposes, and these flights usually do not have many people on board.

[5]https://www.ntsb.gov/investigations/data/Documents/datafiles/PhaseofFlightDefinitions.pdf

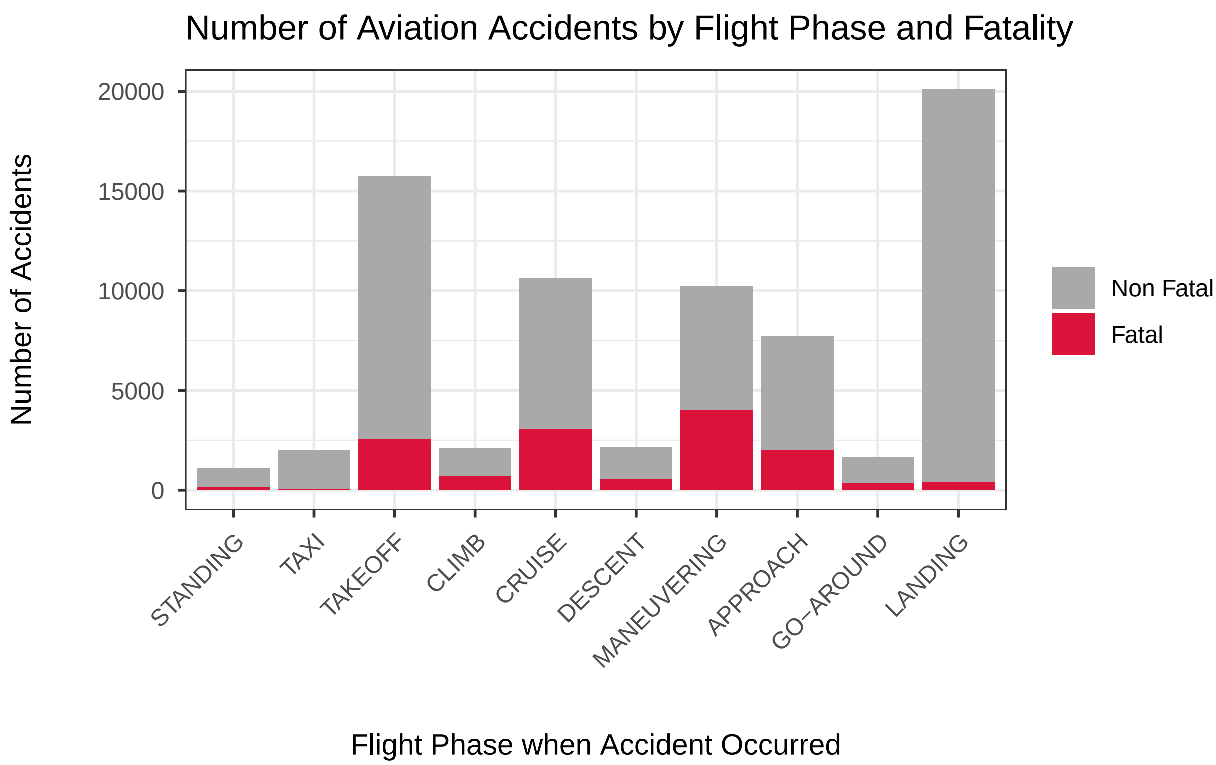


Figure 1: The number of aviation accidents for different flight phases. More accidents happen during landing and take off, but most of those accidents are not fatal. The highest numbers of fatal accidents happen during maneuvering, cruise, take-off, and approach.

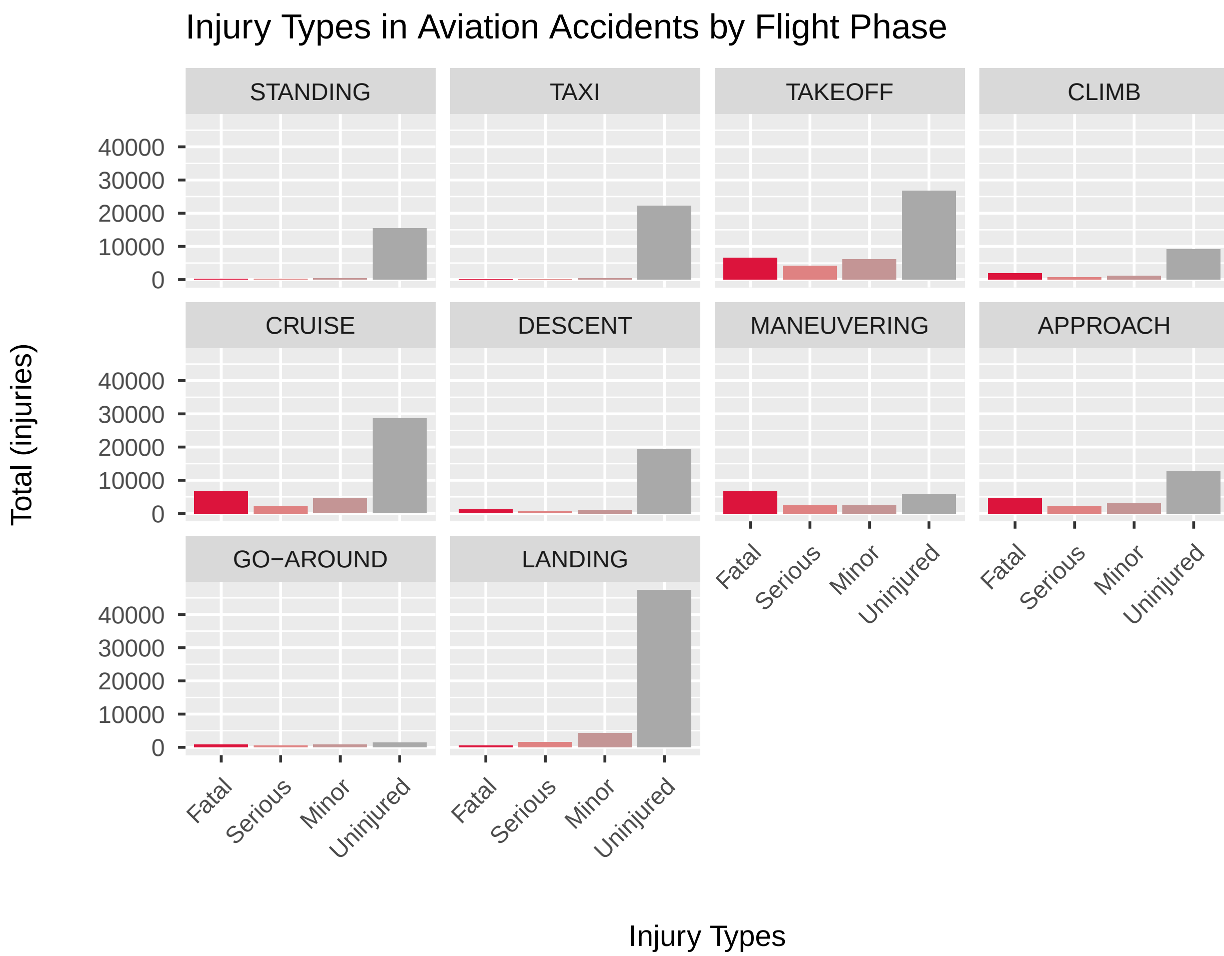


Figure 2: The number of injuries sustained in aviation accidents across different flight phases. Maneuvering, cruise, and take-off have the highest number of fatal injuries in the data. Even though maneuvering has shown to have far more fatal accidents, the number of fatal injuries is not far superior. Most of the flights that got into accidents during the maneuvering phase are flights for personal, aerial application, and instructional purposes. Therefore, they do not have a lot of souls on board.

Statistical Procedure

Using the number of fatal injuries and the number of nonfatal injuries (including those uninjured) in each accident, we will construct a model for fatality proportion based on flight phases. We use the logistic binomial model, with the number of fatal injuries representing the number of 'success' in the binomial model.

$$y_i \sim Binomial(n_i, p_i)$$
$$p_i = logit^{-1}(X_i\beta),$$

where X is a matrix of predictors consisting of the flight phases, the number of fatal injuries, and the number of non-fatal injuries. p_i is the probability of a person being fatally injured from a flight accident that occurs during the flight phase x_i. n_i is the number of souls on board or the total of fatal and non-fatal injuries. β is the coefficient of the linear model associated with the different flight phases.

```
## stan_glm
##  family:       binomial [logit]
##  formula:      cbind(Total.Fatal.Injuries, Total.Non.Fatal) ~ Broad.Phase.of.Flight -
##     1
##  observations: 73514
##  predictors:   10
## ------
##                                   Median MAD_SD
## Broad.Phase.of.FlightSTANDING    -4.41   0.07
## Broad.Phase.of.FlightTAXI        -5.50   0.10
## Broad.Phase.of.FlightTAKEOFF     -1.74   0.01
## Broad.Phase.of.FlightCLIMB       -1.78   0.03
## Broad.Phase.of.FlightCRUISE      -1.64   0.01
## Broad.Phase.of.FlightDESCENT     -2.88   0.03
## Broad.Phase.of.FlightMANEUVERING -0.50   0.02
## Broad.Phase.of.FlightAPPROACH    -1.38   0.02
## Broad.Phase.of.FlightGO-AROUND   -1.16   0.04
## Broad.Phase.of.FlightLANDING     -4.48   0.04
##
## ------
## * For help interpreting the printed output see ?print.stanreg
## * For info on the priors used see ?prior_summary.stanreg
```

The standard errors of the estimated coefficients are relatively small, which means there is not much uncertainty in the logit scale. The estimated coefficients are in the logit scale, but since logit inverse is an increasing function, the flight phase with the largest coefficient would be the flight phase associated with the largest estimated probability of being fatally injured in an accident. We can see from the graph below that maneuvering is associated with the largest probability of being fatally injured should an accident happen during that phase. This is consistent with what we have seen before in the data visualization.

The table below presents the probability interpretation of the coefficients for each flight phase.

Table 2: Result from the Logistic Binomial model

Flight Phase	Linear Coefficients	Probability of Being Fatally Injured	Lower Bound 95% CI	Upper Bound 95% CI
Standing	-4.4092603	0.01	0.01	0.01
Taxi	-5.4986522	0.00	0.00	0.00
Take Off	-1.7368456	0.15	0.15	0.15

Flight Phase	Linear Coefficients	Probability of Being Fatally Injured	Lower Bound 95% CI	Upper Bound 95% CI
Climb	-1.7752131	0.14	0.14	0.15
Cruise	-1.6394277	0.16	0.16	0.17
Descent	-2.8764765	0.05	0.05	0.06
Maneuvering	-0.4963727	0.38	0.37	0.39
Approach	-1.3832696	0.20	0.20	0.21
Go-Around	-1.1597394	0.24	0.22	0.25
Landing	-4.4778970	0.01	0.01	0.01

According to the model, the phase associated with the second-highest probability of being fatally injured is go-around, which is interesting because it did not stand out before in the data visualizations. From Figure 2, we see that the injury numbers for go-around is much lower compared to the other flight phases. However, for accidents that happen during the go-around phase, the number of fatally injured people is almost the same as the number of uninjured people. This could explain why the statistical model assigns a relatively high probability of being fatally injured in an accident that occurs during the go-around phase. Furthermore, when an airplane has to do a go-around, it usually means that the initial landing attempt is unsuccessful. This could imply the presence of other risk factors such as bad weather, technical issues, etc.

We note that the independence of error assumption is violated in the model. When they are all in the same aircraft, the probability of being fatally injured from one person to another is not independent. We also acknowledge that an aviation accident usually happens due to various factors, which is not accommodated in the simple statistical model we are using. However, since the goal of the study is not necessarily to find a predictive model but rather to learn from the historical data if there is a flight phase that is associated with more danger or fatality, we think the model could still be a reasonable reference.

We perform a simple posterior check by using a random subset of the data. A random selection of 200 accidents is selected from the data, and we compare the number of fatalities with the first five simulations from the model, as shown in Figure 4. We see that the simulations mostly underestimate the number of accidents with - injuries. But the simulations do not capture the variation in the data. The data shows at least one accident with more than 200 fatal injuries, but none of the simulations nearly capture that. This is a case of overdispersion, which is common in a logistic binomial regression model.

This statistical model could potentially be improved through further study and analysis on:

- overdispersion, since the variation in the data is larger than predicted by the model;
- a mixed model or latent model, using two models for the probability of an accident being fatal and the probability of being fatally injured.

Discussion

Referring back to the research question, from this data, we see that maneuvering seems to be the flight phase associated with the highest probability of being fatally injured. Even though more accidents seem to happen during the landing and take-off phases, most of these accidents are not fatal. The maneuvering phase has the highest number of fatal accidents in the data set and is associated with the highest probability of a person onboard being fatally injured. The statistical model using logistic binomial regression agrees that an accident that happens during maneuvering phase has a higher probability of being fatally injured than accidents that happen during other phases. This concurs with a claim by FAA, where it also explains that the maneuvering phase involves “turning, climbing, or descending close to the ground”[6].

[6]https://www.faa.gov/news/safety_briefing/2018/media/SE_Topic_18_08.pdf

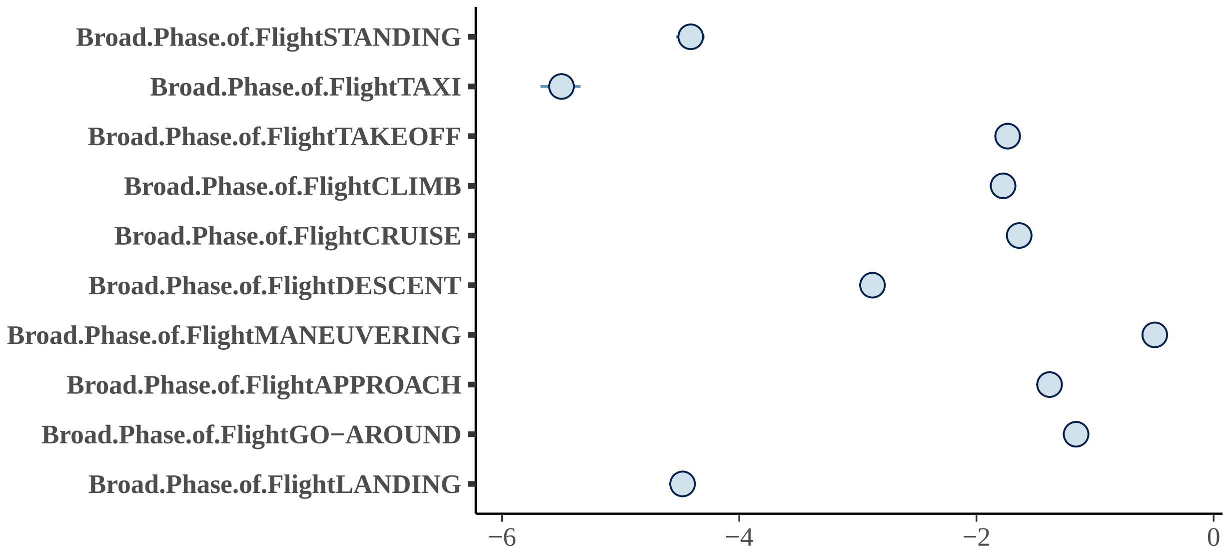


Figure 3: Plot of the linear coefficients from the logistic binomial regression model. The coefficients correspond with the probability of being fatally injured from an accident during a particular flight phase.

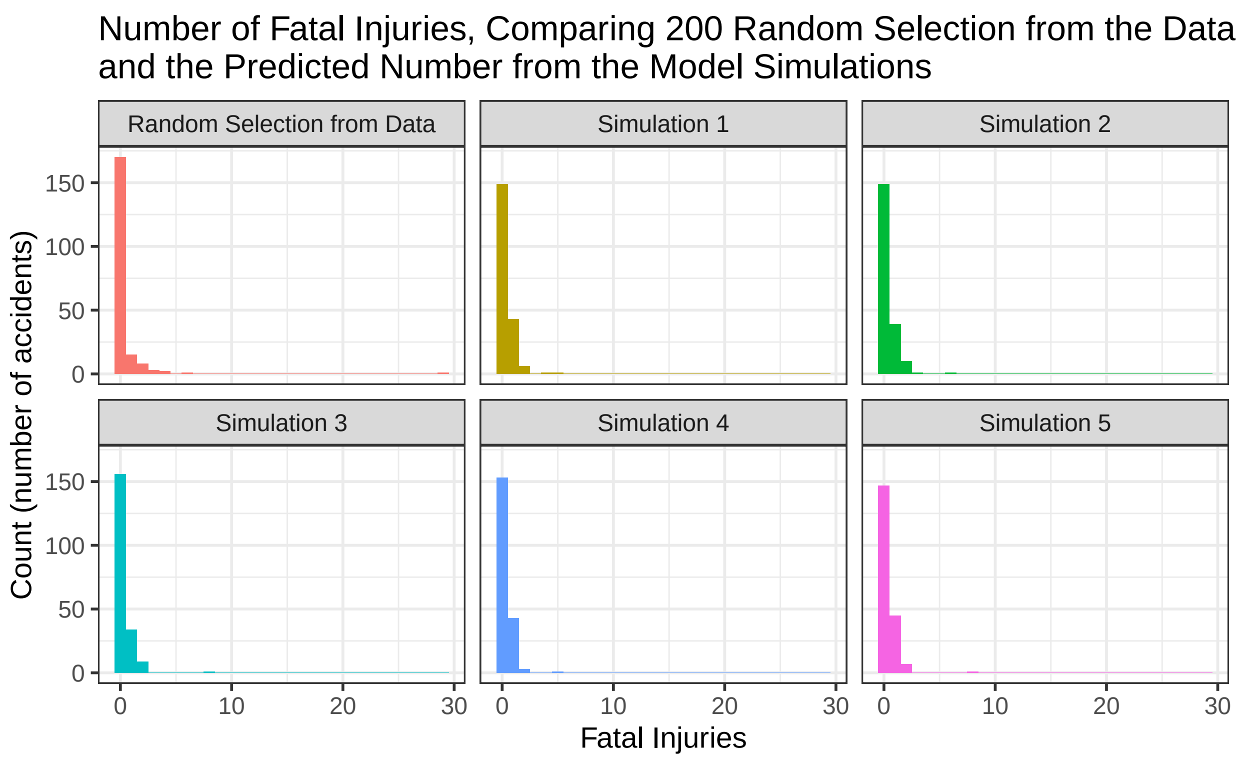


Figure 4: The model simulations mostly underestimate the number of 0 fatalities compared with the random subset of the data. The simulations also do not capture the variation in the data very well. This is a case of overdispersion.

Other phases that are considerably more dangerous are cruise, take off, and approach. The go-around phase also appears among the more dangerous phases, according to the statistical model.

Since this is an observational study, we can only learn of the association between the flight phases when an accident occurs and the probability of being fatally injured. The greater danger is not necessarily caused by the maneuvering flight phase. Many factors cause an aviation accident. It is possible that the maneuvering phase, compared to other flight phases, involves more difficult tasks to perform, and is highly dependent on the nearby terrain and weather, such that it exposes the aircraft to various factors that could cause an accident. Moreover, we acknowledge that many aviation accidents do not have clear information about the flight phase, and because of that, those can not be included in this study and we might not have a fair representation.

References

Antonacci, Andrea. 2020. "Exploring the Ntsb Aviation Accident Database." *GitHub Repository*. https://andreantonacci.github.io/aviation-accidents/; GitHub.

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Wickham, Hadley, Winston Chang, Lionel Henry, Thomas Lin Pedersen, Kohske Takahashi, Claus Wilke, Kara Woo, Hiroaki Yutani, and Dewey Dunnington. 2020. *Ggplot2: Create Elegant Data Visualisations Using the Grammar of Graphics*. https://CRAN.R-project.org/package=ggplot2.

Wickham, Hadley, Romain François, Lionel Henry, and Kirill Müller. 2020. *Dplyr: A Grammar of Data Manipulation*. https://CRAN.R-project.org/package=dplyr.

Xie, Yihui. 2020. *Knitr: A General-Purpose Package for Dynamic Report Generation in R*. https://CRAN.R-project.org/package=knitr.


```
# https://www.rapidtables.com/web/color/red-color.html
# https://bookdown.org/yihui/rmarkdown-cookbook/kable.html
```

Appendix

The code used in this paper is found below.

```
knitr::opts_chunk$set(echo = TRUE)
library(tidyverse)
library(rstanarm)
library(knitr)
library(kableExtra)
library(ggplot2)
data_raw <- read.csv("AviationData.csv") %>%
      filter(Investigation.Type == "Accident") %>%
      filter(Broad.Phase.of.Flight != "") %>%
```

```r
      filter(Broad.Phase.of.Flight != "UNKNOWN")%>%
   filter(Broad.Phase.of.Flight != "OTHER")
data_survive <- data_raw[!duplicated(data_raw$Event.Id),] #19200 row 19200 unique

data_survive$Total.Fatal.Injuries[is.na(data_survive$Total.Fatal.Injuries)] <- 0
data_survive$Total.Minor.Injuries[is.na(data_survive$Total.Minor.Injuries)] <- 0
data_survive$Total.Serious.Injuries[is.na(data_survive$Total.Serious.Injuries)] <- 0
data_survive$Total.Uninjured[is.na(data_survive$Total.Uninjured)] <- 0
data_survive <- data_survive %>%
      mutate(Total.Non.Fatal= Total.Serious.Injuries+Total.Minor.Injuries+Total.Uninjured) %>%
      mutate(Total.Souls.Onboard = Total.Non.Fatal+Total.Fatal.Injuries) %>%
      mutate(Is.Fatal = factor(as.integer(Total.Fatal.Injuries != 0))) %>%
      filter(Total.Souls.Onboard > 0) %>%
   mutate(Fatality.Prop = Total.Fatal.Injuries/Total.Souls.Onboard)
data_survive$Broad.Phase.of.Flight <- factor(data_survive$Broad.Phase.of.Flight,
                                             levels= c("STANDING", "TAXI", "TAKEOFF",
                                                       "CLIMB","CRUISE",
                                                       "DESCENT","MANEUVERING",
                                                       "APPROACH","GO-AROUND",
                                                       "LANDING"))

preview <- data_survive[c(12,64,223,1176,5912,10141),c(4,5,24,25,26,27,29)]
knitr::kable(preview, "pipe", booktabs=T,
             col.names = c("Date", "Location", "Total Fatal Injuries",
                           "Total Serious Injuries", "Total Minor Injuries",
                           "Total Uninjured", "Flight Phase"),
             row.names = F, align = "llccccl",
             caption = "Preview of the NTSB Aviation Accident Data Set")
tunjuk <- data_survive[,c(24,25,26,27,33,29)]
tunjuk$Broad.Phase.of.Flight <- factor(tunjuk$Broad.Phase.of.Flight)
summary(tunjuk, digits = 0)


data_survive %>% ggplot(aes(x=Broad.Phase.of.Flight, fill=Is.Fatal)) +
      geom_bar(position = position_stack()) +
      labs(title = "Number of Aviation Accidents by Flight Phase and Fatality",
           x = "Flight Phase when Accident Occurred", y = "Number of Accidents",
           fill = " ") +
   scale_fill_manual(values=c("#A9A9A9","#DC143C"),
                     labels = c("Non Fatal","Fatal")) +
   theme_bw() +
   theme(axis.text.x = element_text(margin = margin(t = 5, b = 20),
                                    angle = 45, hjust = 1),
            axis.text.y = element_text(margin = margin(r = 5, l = 20)),
            plot.title = element_text(vjust=2))



library(dplyr)
sums <- data_survive %>% group_by(Broad.Phase.of.Flight) %>%
   summarise(Fatal.Injuries = sum(Total.Fatal.Injuries),
             Serious.Injuries = sum(Total.Serious.Injuries),
             Minor.Injuries = sum(Total.Minor.Injuries),
```

```r
              Uninjured = sum(Total.Uninjured))
sums <- as.data.frame(sums)
sums_bar <- tibble(Sums = stack(sums[2:5])[,1] ,
                   Injury.Type = rep(c('Fatal', 'Serious', 'Minor',
                                       'Uninjured'), each=10),
                   Phase = rep(c('STANDING', 'TAXI', 'TAKEOFF','CLIMB',
                                 'CRUISE','DESCENT','MANEUVERING','APPROACH',
                                 'GO-AROUND','LANDING'),4))
sums_bar$Phase <- factor(sums_bar$Phase,
                         levels = c('STANDING', 'TAXI', 'TAKEOFF','CLIMB',
                                    'CRUISE','DESCENT','MANEUVERING','APPROACH',
                                    'GO-AROUND','LANDING'))
sums_bar$Injury.Type <- factor(sums_bar$Injury.Type,
                               levels = c('Fatal', 'Serious',
                               'Minor', 'Uninjured'))

sums_bar %>% ggplot(aes(x=Injury.Type, fill = Injury.Type)) +
   geom_bar(aes(y=Sums), stat = "sum") +
   scale_fill_manual(values=c("#DC143C","#DF8282",
                              "#C49595","#A9A9A9")) +
   facet_wrap(.~Phase) + xlab("Injury Type") + ylab("Total (persons)") +
   ggtitle("Injury Types in Aviation Accidents by Flight Phase")  +
   theme(legend.position = "none") +
   theme(axis.text.y = element_text(margin = margin(r = 5, l = 20)),
         plot.title = element_text(vjust=2))


set.seed(20210216)
fit_logit <- stan_glm(cbind(Total.Fatal.Injuries,Total.Non.Fatal)~Broad.Phase.of.Flight-1,
                        family = binomial(link = "logit"),
                        data = data_survive, refresh=0)
print(fit_logit, digits = 2)


plot(fit_logit)

fit_logit_tbl <- tibble(Broad.Phase.of.Flight = (c("Standing",
                                                   "Taxi",
                     "Take Off","Climb","Cruise","Descent",
                    "Maneuvering","Approach","Go-Around","Landing")),
                     Coef = fit_logit$coefficients,
                     Prob = round(invlogit(fit_logit$coefficients),2),
                     ConfInt.low = invlogit(fit_logit$coefficients-2*fit_logit$ses),
                     ConfInt.up = invlogit(fit_logit$coefficients+2*fit_logit$ses))
knitr::kable(fit_logit_tbl, "pipe",
             col.names = c("Flight Phase","Linear Coefficients",
                           "Probability of Being Fatally Injured",
                           "Lower Bound 95% CI", "Upper Bound 95% CI"),
             row.names = F,
             align = "lcccc",
             caption = "Result from the Logistic Binomial model")
```

```
set.seed(20210216)
selection <- sample(1:nrow(data_survive),200)
data_check<- select(data_survive,c(Broad.Phase.of.Flight,
                                   Total.Fatal.Injuries,Total.Non.Fatal))[selection,]
posterior_check <- posterior_predict(fit_logit, data_check)
for_resid <- tibble(Fatal = c(data_check$Total.Fatal.Injuries,
                                  posterior_check[1,],
                                  posterior_check[2,],
                                  posterior_check[3,],
                              posterior_check[4,],
                              posterior_check[5,]),
                    From = rep(c("Random Selection from Data",
                                 "Simulation 1",
                                 "Simulation 2","Simulation 3",
                                 "Simulation 4", "Simulation 5"),
                               each=200))
for_resid %>% ggplot(aes(x=Fatal, fill=From)) +
   geom_histogram(binwidth = 1) + facet_wrap(.~From) + theme_bw() +
   theme(legend.position = 'none') + xlab("Fatal Injuries (persons)") +
   ylab("Count (number of accidents)")+
   ggtitle("Number of Fatal Injuries, Comparing 100 Random Selection
           from the Data \n and the Predicted Number from the Model Simulations ")
```