Professor McDonald
FNCE 5352 – Financial Programming and Modeling
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Solutions to February 25 Assignment

5.2.4 Exercise 1

Find all flights that

1. Had an arrival delay of two or more hours
2. Flew to Houston (IAH or HOU)
3. Were operated by United, American, or Delta
4. Departed in summer (July, August, and September)
5. Arrived more than two hours late, but didn’t leave late
6. Were delayed by at least an hour, but made up over 30 minutes in flight
7. Departed between midnight and 6 am (inclusive)

The answer to each part follows.

1. Since the `arr_delay` variable is measured in minutes, find flights with an arrival delay of 120 or more minutes.

```
filter(flights, arr_delay >= 120)
#> # A tibble: 10,200 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     1     1      811            630       101     1047
#> 2  2013     1     1      848           1835       853     1001
#> 3  2013     1     1      957            733       144     1056
#> 4  2013     1     1     1114            900       134     1447
#> 5  2013     1     1     1505           1310       115     1638
#> 6  2013     1     1     1525           1340       105     1831
#> # … with 1.019e+04 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

2. The flights that flew to Houston are those flights where the destination (`dest`) is either “IAH” or “HOU”.

```
filter(flights, dest == "IAH" | dest == "HOU")
#> # A tibble: 9,313 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     1     1      517            515         2      830
#> 2  2013     1     1      533            529         4      850
#> 3  2013     1     1      623            627        -4      933
#> 4  2013     1     1      728            732        -4     1041
#> 5  2013     1     1      739            739         0     1104
#> 6  2013     1     1      908            908         0     1228
#> # … with 9,307 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

However, using `%in%` is more compact and would scale to cases where there were more than two airports we were interested in.

```
filter(flights, dest %in% c("IAH", "HOU"))
#> # A tibble: 9,313 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     1     1      517            515         2      830
#> 2  2013     1     1      533            529         4      850
#> 3  2013     1     1      623            627        -4      933
#> 4  2013     1     1      728            732        -4     1041
#> 5  2013     1     1      739            739         0     1104
#> 6  2013     1     1      908            908         0     1228
#> # … with 9,307 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

3. In the `flights` dataset, the column `carrier` indicates the airline, but it uses two-character carrier codes. We can find the carrier codes for the airlines in the `airlines` dataset. Since the carrier code dataset only has 16 rows, and the names of the airlines in that dataset are not exactly “United”, “American”, or “Delta”, it is easiest to manually look up their carrier codes in that data.

```
airlines
#> # A tibble: 16 x 2
#>   carrier name
#>   <chr>   <chr>
#> 1 9E      Endeavor Air Inc.
#> 2 AA      American Airlines Inc.
#> 3 AS      Alaska Airlines Inc.
#> 4 B6      JetBlue Airways
#> 5 DL      Delta Air Lines Inc.
#> 6 EV      ExpressJet Airlines Inc.
#> # … with 10 more rows
```

The carrier code for Delta is `"DL"`, for American is `"AA"`, and for United is `"UA"`. Using these carriers codes, we check whether `carrier` is one of those.

```
filter(flights, carrier %in% c("AA", "DL", "UA"))
#> # A tibble: 139,504 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     1     1      517            515         2      830
#> 2  2013     1     1      533            529         4      850
#> 3  2013     1     1      542            540         2      923
#> 4  2013     1     1      554            600        -6      812
#> 5  2013     1     1      554            558        -4      740
#> 6  2013     1     1      558            600        -2      753
#> # … with 1.395e+05 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

4. The variable `month` has the month, and it is numeric. So, the summer flights are those that departed in months 7 (July), 8 (August), and 9 (September).

```
filter(flights, month >= 7, month <= 9)
```

```
#> # A tibble: 86,326 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     7     1        1           2029       212      236
#> 2  2013     7     1        2           2359         3      344
#> 3  2013     7     1       29           2245       104      151
#> 4  2013     7     1       43           2130       193      322
#> 5  2013     7     1       44           2150       174      300
#> 6  2013     7     1       46           2051       235      304
#> # … with 8.632e+04 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

The `%in%` operator is an alternative. If the `:` operator is used to specify the integer range, the expression is readable and compact.

```
filter(flights, month %in% 7:9)
#> # A tibble: 86,326 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     7     1        1           2029       212      236
#> 2  2013     7     1        2           2359         3      344
#> 3  2013     7     1       29           2245       104      151
#> 4  2013     7     1       43           2130       193      322
#> 5  2013     7     1       44           2150       174      300
#> 6  2013     7     1       46           2051       235      304
#> # … with 8.632e+04 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

We could also use the `|` operator. However, the `|` does not scale to many choices. Even with only three choices, it is quite verbose.

```
filter(flights, month == 7 | month == 8 | month == 9)
#> # A tibble: 86,326 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     7     1        1           2029       212      236
#> 2  2013     7     1        2           2359         3      344
#> 3  2013     7     1       29           2245       104      151
#> 4  2013     7     1       43           2130       193      322
#> 5  2013     7     1       44           2150       174      300
#> 6  2013     7     1       46           2051       235      304
#> # … with 8.632e+04 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

We can also use the `between()` function as shown in Exercise 5.2.2.

5. Flights that arrived more than two hours late, but didn’t leave late will have an arrival delay of more than 120 minutes (`arr_delay > 120`) and a non-positive departure delay (`dep_delay <= 0`).

```
filter(flights, arr_delay > 120, dep_delay <= 0)
#> # A tibble: 29 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     1    27     1419           1420        -1     1754
#> 2  2013    10     7     1350           1350         0     1736
#> 3  2013    10     7     1357           1359        -2     1858
#> 4  2013    10    16      657            700        -3     1258
#> 5  2013    11     1      658            700        -2     1329
#> 6  2013     3    18     1844           1847        -3       39
#> # … with 23 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

6. Were delayed by at least an hour, but made up over 30 minutes in flight. If a flight was delayed by at least an hour, then `dep_delay >= 60`. If the flight didn't make up any time in the air, then its arrival would be delayed by the same amount as its departure, meaning `dep_delay == arr_delay`, or alternatively, `dep_delay - arr_delay == 0`. If it makes up over 30 minutes in the air, then the arrival delay must be at least 30 minutes less than the departure delay, which is stated as `dep_delay - arr_delay > 30`.

   ```
   filter(flights, dep_delay >= 60, dep_delay - arr_delay > 30)
   #> # A tibble: 1,844 x 19
   #>    year month   day dep_time sched_dep_time dep_delay arr_time
   #>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
   #> 1  2013     1     1     2205           1720       285       46
   #> 2  2013     1     1     2326           2130       116      131
   #> 3  2013     1     3     1503           1221       162     1803
   #> 4  2013     1     3     1839           1700        99     2056
   #> 5  2013     1     3     1850           1745        65     2148
   #> 6  2013     1     3     1941           1759       102     2246
   #> # … with 1,838 more rows, and 12 more variables: sched_arr_time <int>,
   #> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
   #> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
   #> #   minute <dbl>, time_hour <dttm>
   ```

7. Finding flights that departed between midnight and 6 a.m. is complicated by the way in which times are represented in the data. In `dep_time`, midnight is represented by `2400`, not `0`. This means we cannot simply check that `dep_time < 600`, because we also have to consider the special case of midnight.

   ```
   filter(flights, dep_time <= 600 | dep_time == 2400)
   #> # A tibble: 9,373 x 19
   #>    year month   day dep_time sched_dep_time dep_delay arr_time
   #>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
   #> 1  2013     1     1      517            515         2      830
   #> 2  2013     1     1      533            529         4      850
   #> 3  2013     1     1      542            540         2      923
   #> 4  2013     1     1      544            545        -1     1004
   #> 5  2013     1     1      554            600        -6      812
   #> 6  2013     1     1      554            558        -4      740
   #> # … with 9,367 more rows, and 12 more variables: sched_arr_time <int>,
   #> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
   #> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
   #> #   minute <dbl>, time_hour <dttm>
   ```

   Alternatively, we could use the modulo operator, `%%`. The modulo operator returns the remainder of division. Let's see how how this affects our times.

   ```
   c(600, 1200, 2400) %% 2400
   #> [1]  600 1200    0
   ```

Since `2400 %% 2400 == 0` and all other times are left unchanged, we can compare the result of the modulo operation to `600`,

```
filter(flights, dep_time %% 2400 <= 600)
#> # A tibble: 9,373 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     1     1      517            515         2      830
#> 2  2013     1     1      533            529         4      850
#> 3  2013     1     1      542            540         2      923
#> 4  2013     1     1      544            545        -1     1004
#> 5  2013     1     1      554            600        -6      812
#> 6  2013     1     1      554            558        -4      740
#> # … with 9,367 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

This filter expression is more compact, but its readability will depends on the familiarity of the reader with modular arithmetic.

5.2.4 Exercise 3

How many flights have a missing `dep_time`? What other variables are missing? What might these rows represent?

Find the rows of flights with a missing departure time (`dep_time`) using the `is.na()` function.

```
filter(flights, is.na(dep_time))
#> # A tibble: 8,255 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     1     1       NA           1630        NA       NA
#> 2  2013     1     1       NA           1935        NA       NA
#> 3  2013     1     1       NA           1500        NA       NA
#> 4  2013     1     1       NA            600        NA       NA
#> 5  2013     1     2       NA           1540        NA       NA
#> 6  2013     1     2       NA           1620        NA       NA
#> # … with 8,249 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

Notably, the arrival time (`arr_time`) is also missing for these rows. These seem to be cancelled flights.

5.3.1 Exercise 1

How could you use `arrange()` to sort all missing values to the start? (Hint: use `is.na()`).

The `arrange()` function puts `NA` values last.

```
arrange(flights, dep_time) %>%
  tail()
#> # A tibble: 6 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     9    30       NA           1842        NA       NA
#> 2  2013     9    30       NA           1455        NA       NA
#> 3  2013     9    30       NA           2200        NA       NA
#> 4  2013     9    30       NA           1210        NA       NA
#> 5  2013     9    30       NA           1159        NA       NA
#> 6  2013     9    30       NA            840        NA       NA
#> # … with 12 more variables: sched_arr_time <int>, arr_delay <dbl>,
#> #   carrier <chr>, flight <int>, tailnum <chr>, origin <chr>, dest <chr>,
#> #   air_time <dbl>, distance <dbl>, hour <dbl>, minute <dbl>,
#> #   time_hour <dttm>
```

Using `desc()` does not change that.

```
arrange(flights, desc(dep_time))
#> # A tibble: 336,776 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013    10    30     2400           2359         1      327
#> 2  2013    11    27     2400           2359         1      515
#> 3  2013    12     5     2400           2359         1      427
#> 4  2013    12     9     2400           2359         1      432
#> 5  2013    12     9     2400           2250        70       59
#> 6  2013    12    13     2400           2359         1      432
#> # … with 3.368e+05 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

To put `NA` values first, we can add an indicator of whether the column has a missing value. Then we sort by the missing indicator column and the the column of interest. For example, to sort the data frame by departure time (`dep_time`) in ascending order but `NA` values first, run the following.

```
arrange(flights, desc(is.na(dep_time)), dep_time)
#> # A tibble: 336,776 x 19
#>    year month   day dep_time sched_dep_time dep_delay arr_time
#>   <int> <int> <int>    <int>          <int>     <dbl>    <int>
#> 1  2013     1     1       NA           1630        NA       NA
#> 2  2013     1     1       NA           1935        NA       NA
#> 3  2013     1     1       NA           1500        NA       NA
#> 4  2013     1     1       NA            600        NA       NA
#> 5  2013     1     2       NA           1540        NA       NA
#> 6  2013     1     2       NA           1620        NA       NA
#> # … with 3.368e+05 more rows, and 12 more variables: sched_arr_time <int>,
#> #   arr_delay <dbl>, carrier <chr>, flight <int>, tailnum <chr>,
#> #   origin <chr>, dest <chr>, air_time <dbl>, distance <dbl>, hour <dbl>,
#> #   minute <dbl>, time_hour <dttm>
```

The `flights` will first be sorted by `desc(is.na(dep_time))`.

Since `desc(is.na(dep_time))` is either `TRUE` when `dep_time` is missing, or `FALSE`, when it is not, the rows with missing values of `dep_time` will come first, since `TRUE > FALSE`.

5.5.2 Exercise 2

Compare `air_time` with `arr_time - dep_time`. What do you expect to see? What do you see? What do you need to do to fix it?
I expect that `air_time` is the difference between the arrival (`arr_time`) and departure times (`dep_time`). In other words, `air_time = arr_time - dep_time`.
To check that this relationship, I'll first need to convert the times to a form more amenable to arithmetic operations using the same calculations as the previous exercise.

```
flights_airtime <-
  mutate(flights,
    dep_time = (dep_time %/% 100 * 60 + dep_time %% 100) %% 1440,
    arr_time = (arr_time %/% 100 * 60 + arr_time %% 100) %% 1440,
    air_time_diff = air_time - arr_time + dep_time
  )
```

So, does `air_time = arr_time - dep_time`? If so, there should be no flights with non-zero values of `air_time_diff`.

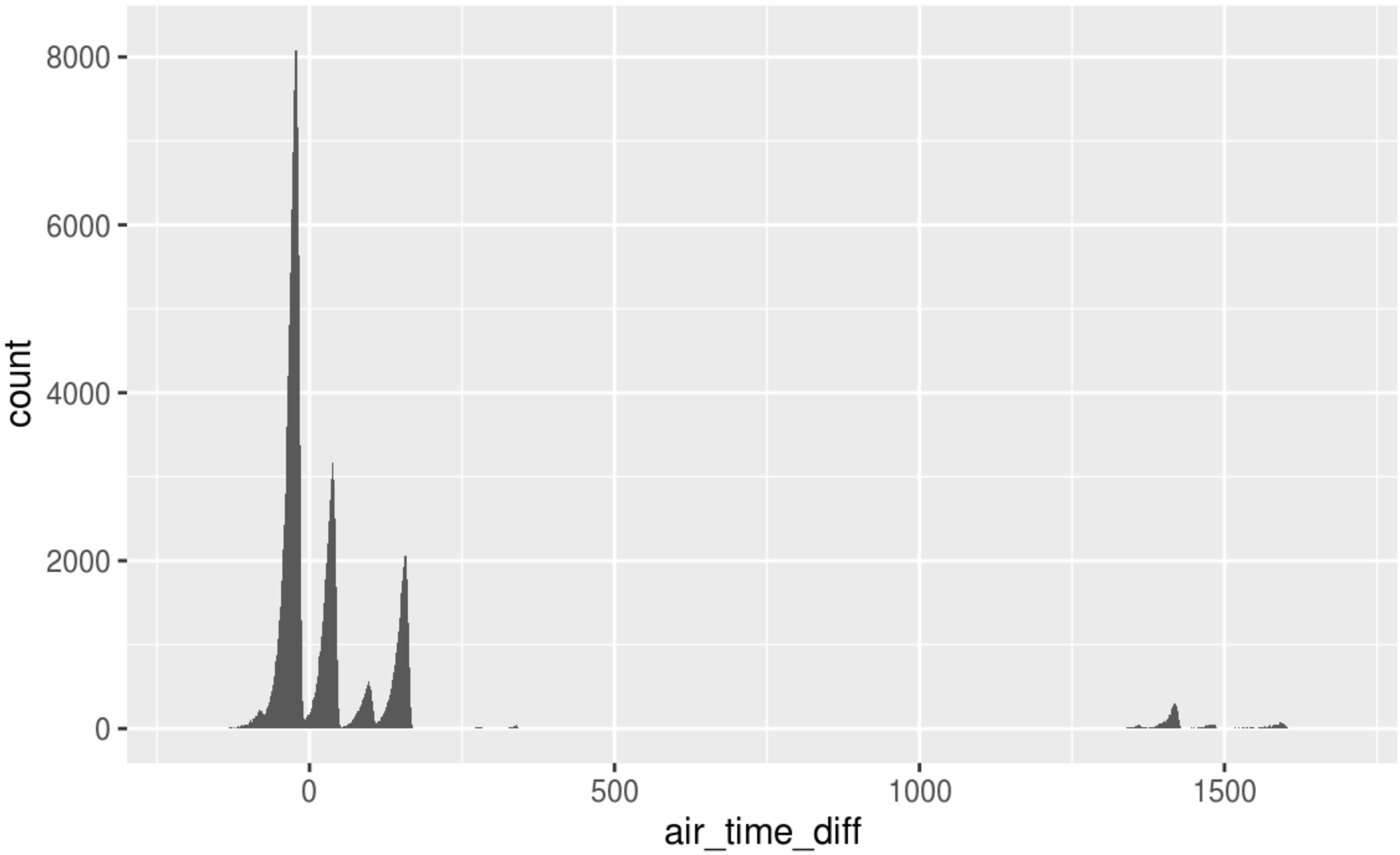
```
nrow(filter(flights_airtime, air_time_diff != 0))
#> [1] 327150
```

It turns out that there are many flights for which `air_time != arr_time - dep_time`. Other than data errors, I can think of two reasons why `air_time` would not equal `arr_time - dep_time`.

1. The flight passes midnight, so `arr_time < dep_time`. In these cases, the difference in airtime should be by 24 hours (1,440 minutes).
2. The flight crosses time zones, and the total air time will be off by hours (multiples of 60). All flights in `flights` departed from New York City and are domestic flights in the US. This means that flights will all be to the same or more westerly time zones. Given the time-zones in the US, the differences due to time-zone should be 60 minutes (Central) 120 minutes (Mountain), 180 minutes (Pacific), 240 minutes (Alaska), or 300 minutes (Hawaii).

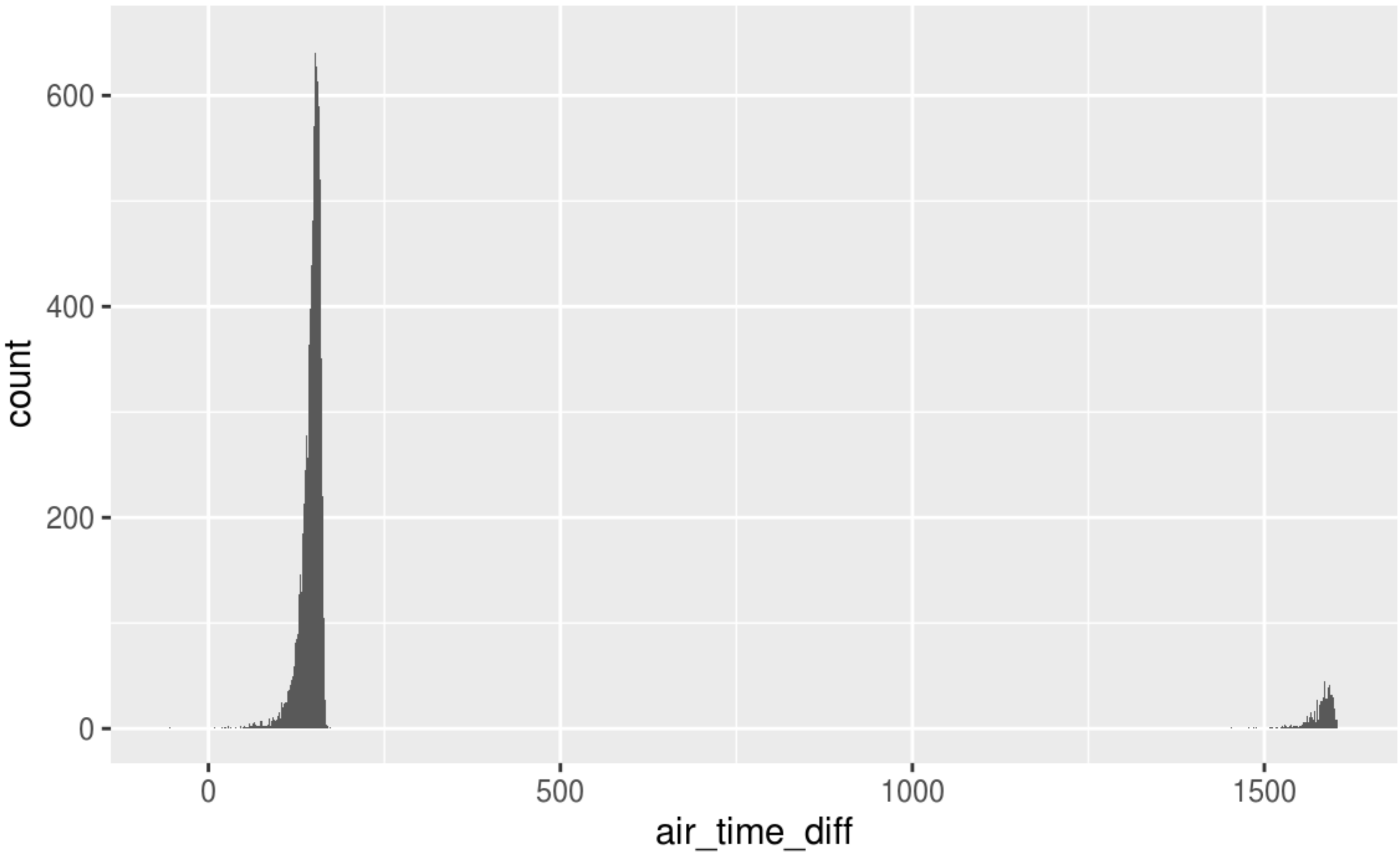
Both of these explanations have clear patterns that I would expect to see if they were true. In particular, in both cases, since time-zones and crossing midnight only affects the hour part of the time, all values of `air_time_diff` should be divisible by 60. I'll visually check this hypothesis by plotting the distribution of `air_time_diff`. If those two explanations are correct, distribution of `air_time_diff`should comprise only spikes at multiples of 60.

```
ggplot(flights_airtime, aes(x = air_time_diff)) +
  geom_histogram(binwidth = 1)
#> Warning: Removed 9430 rows containing non-finite values (stat_bin).
```



This is not the case. While, the distribution of `air_time_diff` has modes at multiples of 60 as hypothesized, it shows that there are many flights in which the difference between air time and local arrival and departure times is not divisible by 60.
Let’s also look at flights with Los Angeles as a destination. The discrepancy should be 180 minutes.

```
ggplot(filter(flights_airtime, dest == "LAX"), aes(x = air_time_diff)) +
  geom_histogram(binwidth = 1)
#> Warning: Removed 148 rows containing non-finite values (stat_bin).
```



To fix these time-zone issues, I would want to convert all the times to a date-time to handle overnight flights, and from local time to a common time zone, most likely UTC, to handle flights crossing time-zones. The `tzone` column of `nycflights13::airports` gives the time-zone of each airport. See the "Dates and Times" for an introduction on working with date and time data.

But that still leaves the other differences unexplained. So what else might be going on? There seem to be too many problems for this to be data entry problems, so I'm probably missing something. So, I'll reread the documentation to make sure that I understand the definitions of `arr_time`, `dep_time`, and`air_time`. The documentation contains a link to the source of the `flights` data, https://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=236. This documentation shows that the `flights` data does not contain the variables `TaxiIn`, `TaxiOff`, `WheelsIn`, and `WheelsOff`. It appears that the `air_time` variable refers to flight time, which is defined as the time between wheels-off (take-off) and wheels-in (landing). But the flight time does not include time spent on the runway taxiing to and from gates. With this new understanding of the data, I now know that the relationship between `air_time`, `arr_time`, and `dep_time` is `air_time <= arr_time - dep_time`, supposing that the time zones of `arr_time` and `dep_time` are in the same time zone.

5.5.2 Exercise 5

What does `1:3 + 1:10` return? Why?
The code given in the question returns the following.

```
1:3 + 1:10
#> Warning in 1:3 + 1:10: longer object length is not a multiple of shorter
#> object length
#>  [1]  2  4  6  5  7  9  8 10 12 11
```

This is equivalent to the following.

```
c(1 + 1, 2 + 2, 3 + 3, 1 + 4, 2 + 5, 3 + 6, 1 + 7, 2 + 8, 3 + 9, 1 + 10)
#>  [1]  2  4  6  5  7  9  8 10 12 11
```

When adding two vectors recycles the shorter vector’s values to get vectors of the same length.

The code also produces a warning that the shorter vector is not a multiple of the longer vector. A warning is provided since often, but not always, this indicates a bug in the code.