CONTINUED NHANES USE FOR STANDARD AVERAGE BODY WEIGHT

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ABSTRACT

For use in aircraft weight and balance, a previously defined method to determine standard average weights for body mass of passengers and crew in a manner consistent with guidance from the United States (U.S.) Federal Aviation Administration (FAA), especially Advisory Circular (AC) 120-27 "Aircraft Weight and Balance Control," is applied to data available in 2024 from the Centers for Disease Control and Prevention (CDC) National Health and Nutrition Examination Survey (NHANES). Application of the method to data collected before and after the SARS-CoV-2/COVID-19 pandemic is discussed, and trends are illustrated. Results are applicable to Operation Specification (OpSpec) approval using survey-derived average weight values.

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PROBLEM STATEMENT

In response to changes published by the United States (U.S.) Federal Aviation Administration (FAA) in 2019 and 2020, the Society of Aircraft Performance and Operations Engineers (SAPOE) published a paper titled "NHANES USE FOR STANDARD AVERAGE BODY WEIGHT," dated 14 DEC 2020 (hereafter, "SAPOE 2020"), which defined a method to determine standard average weights for body mass of passengers and crew. Like FAA guidance before it, the SAPOE 2020 method relies heavily on data from the Centers for Disease Control and Prevention (CDC) obtained in the National Health and Nutrition Examination Survey (NHANES).

Since then, CDC NHANES has continued to collect and publish body-mass data, but its data collection schedule and survey design have been modified due to the SARS-CoV-2/COVID-19 pandemic (hereafter, "Covid"). Application of the SAPOE 2020 method to the new data, for use in current aviation operations, requires a review of these changes.

Familiarity with the terms and definitions in SAPOE 2020 is assumed. Formulas from SAPOE 2020 are used extensively, identified here as (2020-N) where (N) is the formula number in the original paper. This paper is referred to as "SAPOE 2024" with newly defined formulas identified using the convention (2024-X) for clarity.

NHANES IN 2020 AND YEARS SINCE

NHANES is a rigorous scientific study of health and nutrition among the U.S., non-institutionalized, civilian population whose scope includes numerous body measurements. Academically rigorous documentation, including Sample Design, Weighting Process, and Analytic Guidelines, is available in a series of papers at https://wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx.

Note: NHANES generally (not exclusively) uses "weight" to mean a numeric scaling factor, as in the common meaning of "weighted average," rather than a measure of gravitational mass. To avoid confusion, this section carefully uses "mass" as the object of gravity and follows the NHANES convention for "weight" despite this paper's use elsewhere of U.S. aviation vernacular, including "weight and balance" for the effect of gravity.

From 1999 until Covid, NHANES was conducted in cycles, each covering two complete calendar years. Cycles were numbered consecutively from 1. At the time of publication of SAPOE 2020, the most recently available data were from cycle 10, collected in 2017 and 2018. SAPOE 2020 followed NHANES Analytic Guidelines in combining each oddnumber cycle with the following even-number cycle to create a four-year cycle. SAPOE 2020 excluded cycles 1 and 2 from its summary because their design requires a different method of variance analysis than all later cycles.

Continuing its established pattern, NHANES started collecting data for cycle 11 at the beginning of 2019, but this effort was discontinued by CDC in March 2020 in response to Covid. Since the data collected for cycle 11 is incomplete, CDC will not publish it alone. However, this data was published in combination with data from cycle 10 as a special cycle, covering 3.2 years, which CDC numbered "66." NHANES Analytic Guidelines indicate survey design weights for cycle 66 were recalculated to be as representative of the population as possible despite incomplete data. However, it also warns that this makes comparison of cycle 66 to other cycles unsuitable for trend analysis. (The recalculated design weights for cycle 66 are labelled WTMECPRP by CDC to distinguish them from WTMEC2YR or the combined WTMEC4YR weights.)

Continuing the now disrupted pattern, cycle 12 would have started at the beginning of 2021 and proceeded through the end of 2022. However, the start of data collection was delayed, and CDC elected to preserve the collection period of two whole years rather than the calendar-year cadence. The resulting cycle 12 covers 2.0 years beginning in August 2021 and ending in August 2023. NHANES does not recommend combining post-Covid data with pre-Covid data.

The following table summarizes these cycle differences:

Table 2024-1: NHANES Data Cycles

Cycle Number	Data Published	Body Measures File Name	Data Collection Begin	Data Collection End	Combined Cycle Design	Note
1	Jun 2002	BMX	Jan 1999	Dec 2000	Designed in advance to combine 1 and 2	
2	May 2004	BMX_B	Jan 2001	Dec 2002		
3	Nov 2005	BMX_C	Jan 2003	Dec 2004	Designed in advance to combine 3 and 4	
4	Nov 2007	BMX_D	Jan 2005	Dec 2006		
5	Sep 2009	BMX_E	Jan 2007	Dec 2008	Designed in advance to combine 5 and 6	
6	Sep 2011	BMX_F	Jan 2009	Dec 2010		
7	Sep 2013	BMX_G	Jan 2011	Dec 2012	Designed in advance to combine 7 and 8	
8	Oct 2015	BMX_H	Jan 2013	Dec 2014		
9	Sep 2017	BMX_I	Jan 2015	Dec 2016	Designed in advance to combine 9 and 10	
10	Feb 2020	BMX_J	Jan 2017	Dec 2018		
11	*Never*	*None*	Jan 2019	Mar 2020	*N/A*	Data collection suspended due to Covid.
66	May 2021	P_BMX	Jan 2017	Mar 2020	Redesign combines 10 and 11	Design weights were recalculated after data collection to combine with cycle 10 despite incomplete data.
12	Sep 2024	BMX_L	Aug 2021	Aug 2023	*TBA*	Start of data collection delayed. Data combination method not yet announced.

NHANES Analytic Guidelines specifies that trend analysis must use a continuous time scale to account for changes in both cycle duration and the cadence of cycle start. Data may be referenced to the midpoint of the data collection period, which is given as 2017.0 for the combined 2015–2018 cycle, 2018.6 for cycle 66, and 2022.7 for cycle 12. (These are decimal fractions of a year, distinct from the "YYYY/MM" format used for whole months in date labels.)

It is important that data variables have consistent definitions when compared across survey cycles. The data variables in cycle 12 data files are consistent with those used by SAPOE 2020 except for age masking. Specifically, this means that to prevent any person surveyed from being identifiable from the data collected about them, data for anyone older than 80 is coded as if they were 80 years old, and data for anyone who was both pregnant and under the age of 20 is coded as if they were 20 years old. NHANES documentation draws attention to pregnancy and age masking because it may move data between categories used by CDC when it creates growth charts from NHANES data for use in other medical contexts. If age, gender, and crew categories defined in SAPOE 2020 are used, no data is moved from one category to another, so the age masking does not change any result. For example, data for any pregnant teen will be in the category "Adult," as defined by FAA, whether coded as 16 years old or as 20 years old. (There is no data for any "Child," as defined by FAA, who is also pregnant in any NHANES data set examined.)

CALCULATIONS USING SAMPLE CODE

Calculations are demonstrated here using "R," a data analysis language accessible to many data analysts and operations engineers, printed in a fixed-width font with executable code shown in `blue`, descriptive comments in `green`, and any output generated in `orange`. Code fragments should be executed in the order presented. The complete R script described is included in Appendix B to this paper.

Since the data variable definitions and file formats for NHANES cycle 12 are consistent with cycles 3 through 10, sample code from SAPOE 2020 will generate correct results for cycle 12 with only two minimal modifications.

The first required modification replaces the single call to `importDataCycles` to import the latest raw data files:

```
# Load the data into memory once each session
RawData <- importDataCycles(12)
```

The second required modification is one added line in function `fmtWTLB`, before `print.data.frame`, to update the years used to label the latest data:

```
cycleData <- mutate(cycleData,
  Years=ifelse(12==cycle4,'2021/08-2023/08',as.character(Years)))
```

Further reorganization of the sample code allows much improved reuse and clarity without modifying the fundamental implementation. Differences from SAPOE 2020, Appendix A, to SAPOE 2024, Appendix B, are discussed here. Unmodified output from the script in Appendix B is shown below. These data values exactly match output in the SAPOE 2020 paper, substantiating that the code reorganization does not change the values in the results.

First, since the NHANES cycles have become more complex and less predictable, all the metadata describing each cycle is grouped into a function called `nhanesCycleDefinitions`. This function must be modified to add future cycles, but it is hoped that such modifications, such as the parity for combination of cycles, can be limited to updating this one location.

For trend analysis, the metadata defined includes the `duration` of each cycle in decimal years and a continuous time scale `trendYear`. Using time relative to a contemporary date preserves all effects of cycle duration and of delayed cycle start, but it better represents available precision for calculation. (For example, the precision implied by rounding 2022.7 to tenths of a year is approximately ±2.5% over a two-year period, not the ±0.0025% implied by counting significant digits in $2.0227 \cdot 10^{+3}$ years.) The choice of the midpoint of the 2015–2018 combined cycle as the reference for relative time is arbitrary and allows convenient comparison to SAPOE 2020.

The function `importRawDataFiles` makes importing raw data files more convenient by downloading only missing cycles without having to comment out code each time the script is run. This function also encapsulates file-naming conventions that differ subtly from the cycle numbering. It would need to be modified if the website locations of the data files change, or if the conventions for variable names inside the data files change.

The function `enrichDataSet` adds unit conversion and category definitions not defined by NHANES but which are needed for this analysis, especially `faaAge`. This function would need to be modified if the conventions for variable names inside the data files change.

To emphasize when the identical method is applied to multiple population subsets, the function `sapoeNHANES` combines calculations SAPOE 2020 identified as `Step0` through `Step5`, together with `NN` for estimating population ratios using Formula (2020-7). This function should not need to change unless the method definition is changed.

The formatting function `fmtWTLB` behaves as before with accommodation for changes in function `sapoeNHANES`. The formatted output columns, defined either in SAPOE 2020 or above, are summarized in the following table.

Table 2024-2: Output Columns and Units

Label	*Meaning*	*Units*
`cycle`	*NHANES raw or combined cycle number*	*none*
`label`	*NHANES cycle description by year and month*	*"YYYY/MM" string (not a number)*
`duration`	*NHANES raw or combined cycle duration*	*decimal years*
`trendYear`	*SAPOE 2024 relative time for trend analysis*	*decimal years*
`cdcAge`	*CDC age category for NHSR*	*none*
`faaAge`	*SAPOE 2020 age category for FAA*	*none*
`gender`	*CDC defined gender, also used for FAA*	*none*
`counts`	*NHANES sample size*	*1*
`WTLB`	*body mass (unclothed, except where indicated)*	*pounds*
`se`	*standard error, using Taylor series linearization*	*pounds*
`n`	*SAPOE 2020 filtered sample size,* n_f	*1*
`NP`	*SAPOE 2020 population quantity,* N	*1*
`W`	*SAPOE 2020 average body mass,* W	*pounds*
`W_*`	*SAPOE 2020 operational body mass,* $[W]$	*pounds*
`S`	*FAA Standard Deviation, using Formula (2020-4)*	*pounds*
`te%`	*FAA Tolerable Error, using Formula (2020-5)*	*unitless % (not pounds)*

Sample code should not be used for NHANES cycles 1 or 2 because Analytic Guidelines recommends variance analysis using a jackknife method, with specified resampling weights, for these cycles but recommends Taylor series linearization using `library(survey)` for all later cycles.

Once these functions are defined, and `setwd` is pointed to the appropriate system-specific location for data files, the following code and output demonstrate matching values to those on pages 11 and 12 of SAPOE 2020, which were compared to statistics published by CDC in National Health Statistics Reports (NHSR) in 2018.

```
RawData <- importRawDataFiles(c(3:10,66,12))

Cycles2 <- nhanesCycleDefinitions(FALSE)
WTLB2YR <- enrichDataSet( RawData, Cycles2 )

# Define survey design parameters for overall dataset, per NHANES Tutorials
NHANES2<-svydesign(data=WTLB2YR, id=~SDMVPSU, strata=~SDMVSTRA, weights=~svyWt, nest=TRUE)

# confirm definitions above here are correct for full NHANES by comparing to
#  https://www.cdc.gov/nchs/data/nhsr/nhsr122-508.pdf
 svyWTLB( subset( NHANES2, NotPregnant ), ~cycle+cdcAge+gender ) %>% fmtWTLB(Cycles2) %>%
  filter( cdcAge=='Adult' & cycle<10 ) # NHSR Table 2 has Adults in these years

   cycle           label duration trendYear cdcAge gender counts  WTLB  se
1      3 2003/01-2004/01        2       -13  Adult   Male   2247 193.5 1.0
2      4 2005/01-2006/01        2       -11  Adult   Male   2242 196.0 1.7
3      5 2007/01-2008/01        2        -9  Adult   Male   2755 194.7 1.4
```

```
4       6 2009/01-2010/01        2        -7  Adult   Male   2896 196.3 1.4
5       7 2011/01-2012/01        2        -5  Adult   Male   2591 194.4 1.4
6       8 2013/01-2014/01        2        -3  Adult   Male   2645 197.0 1.2
7       9 2015/01-2016/01        2        -1  Adult   Male   2584 197.8 1.9
8       3 2003/01-2004/01        2       -13  Adult Female   2201 164.2 1.6
9       4 2005/01-2006/01        2       -11  Adult Female   2129 165.1 1.7
10      5 2007/01-2008/01        2        -9  Adult Female   2805 166.2 1.3
11      6 2009/01-2010/01        2        -7  Adult Female   3039 166.3 0.9
12      7 2011/01-2012/01        2        -5  Adult Female   2602 167.1 1.3
13      8 2013/01-2014/01        2        -3  Adult Female   2823 169.8 1.3
14      9 2015/01-2016/01        2        -1  Adult Female   2757 170.5 1.7
```

(In this and subsequent output, the first column is an automatically generated row number for reference only.)

The following code and output demonstrate matching values to those on page 14 of SAPOE 2020, which were the output from Part 1 under "Method Definition," SAPOE 2020, using combined-cycle data.

```
Cycles4 <- nhanesCycleDefinitions(TRUE )
WTLB4YR <- enrichDataSet( RawData, Cycles4 )

Passengers <- sapoeNHANES( WTLB4YR )
fmtWTLB( Passengers, Cycles4 )

   cycle           label duration trendYear faaAge gender    n   NP     W    S te%
1      4 2003/01-2006/01      4.0     -12.0 Infant   None 1494  2.9  21.8  5.1 1.2
2      6 2007/01-2010/01      4.0      -8.0 Infant   None 1382  2.9  21.1  4.9 1.2
3      8 2011/01-2014/01      4.0      -4.0 Infant   None 1167  2.4  20.9  5.2 1.4
4     10 2015/01-2018/01      4.0       0.0 Infant   None 1118  2.4  21.1  5.0 1.4
5     66 2017/01-2020/03      3.2       1.6 Infant   None  820  2.3  21.2  5.2 1.7
6      4 2003/01-2006/01      4.0     -12.0  Child   None 4087 15.0  62.0 26.4 1.3
7      6 2007/01-2010/01      4.0      -8.0  Child   None 4156 14.8  61.5 26.7 1.3
8      8 2011/01-2014/01      4.0      -4.0  Child   None 4303 14.6  62.4 26.9 1.3
9     10 2015/01-2018/01      4.0       0.0  Child   None 3692 13.7  62.9 26.3 1.3
10    66 2017/01-2020/03      3.2       1.6  Child   None 2835 13.5  63.6 27.2 1.6
11     4 2003/01-2006/01      4.0     -12.0  Adult   Male 5940 39.7 186.1 36.1 0.5
12     6 2007/01-2010/01      4.0      -8.0  Adult   Male 6291 40.1 186.5 37.3 0.5
13     8 2011/01-2014/01      4.0      -4.0  Adult   Male 5879 40.4 186.8 37.1 0.5
14    10 2015/01-2018/01      4.0       0.0  Adult   Male 5689 40.8 189.6 40.5 0.6
15    66 2017/01-2020/03      3.2       1.6  Adult   Male 4559 41.0 190.5 40.1 0.6
16     4 2003/01-2006/01      4.0     -12.0  Adult Female 6321 42.4 155.9 35.1 0.6
17     6 2007/01-2010/01      4.0      -8.0  Adult Female 6435 42.2 157.3 35.3 0.5
18     8 2011/01-2014/01      4.0      -4.0  Adult Female 6125 42.6 159.3 36.4 0.6
19    10 2015/01-2018/01      4.0       0.0  Adult Female 5937 43.1 161.6 37.2 0.6
20    66 2017/01-2020/03      3.2       1.6  Adult Female 4680 43.2 162.7 38.4 0.7
```

The following code and output are the survey-derived averages for body mass calculated in accordance with Part 1 under "Method Definition," SAPOE 2020, using two-year cycle data instead of combined-cycle data.

```
Passengers <- sapoeNHANES( WTLB2YR )
fmtWTLB( Passengers, Cycles2 )

   cycle           label duration trendYear faaAge gender    n   NP     W    S te%
1      3 2003/01-2004/01        2     -13.0 Infant   None  709  2.8  22.0  5.2 1.7
2      4 2005/01-2006/01        2     -11.0 Infant   None  783  3.0  21.5  4.9 1.6
3      5 2007/01-2008/01        2      -9.0 Infant   None  700  2.9  20.8  4.8 1.7
```

```
4       6 2009/01-2010/01         2       -7.0 Infant    None  684  2.9   21.2   5.0 1.8
5       7 2011/01-2012/01         2       -5.0 Infant    None  567  2.3   20.6   5.3 2.1
6       8 2013/01-2014/01         2       -3.0 Infant    None  599  2.5   21.2   5.2 2.0
7       9 2015/01-2016/01         2       -1.0 Infant    None  606  2.5   21.1   4.8 1.8
8      10 2017/01-2018/01         2        1.0 Infant    None  513  2.4   21.1   5.4 2.2
9      12 2021/08-2023/08         2        5.7 Infant    None  230  2.3   21.3   4.5 2.7
10      3 2003/01-2004/01         2      -13.0  Child    None 1921 15.2   63.4 27.5 1.9
11      4 2005/01-2006/01         2      -11.0  Child    None 2167 14.9   60.8 25.4 1.8
12      5 2007/01-2008/01         2       -9.0  Child    None 2061 14.8   60.9 26.4 1.9
13      6 2009/01-2010/01         2       -7.0  Child    None 2095 14.8   62.1 27.0 1.9
14      7 2011/01-2012/01         2       -5.0  Child    None 2142 14.9   62.6 27.5 1.9
15      8 2013/01-2014/01         2       -3.0  Child    None 2167 14.4   62.4 26.6 1.8
16      9 2015/01-2016/01         2       -1.0  Child    None 2057 14.0   62.8 26.5 1.8
17     10 2017/01-2018/01         2        1.0  Child    None 1637 13.5   63.2 26.4 2.0
18     12 2021/08-2023/08         2        5.7  Child    None 1439 13.8   65.8 29.1 2.3
19      3 2003/01-2004/01         2      -13.0  Adult    Male 2992 39.9 185.1 35.1 0.7
20      4 2005/01-2006/01         2      -11.0  Adult    Male 2953 39.6 187.3 37.4 0.7
21      5 2007/01-2008/01         2       -9.0  Adult    Male 3043 40.0 185.2 36.3 0.7
22      6 2009/01-2010/01         2       -7.0  Adult    Male 3246 40.2 187.9 38.1 0.7
23      7 2011/01-2012/01         2       -5.0  Adult    Male 2890 40.4 186.2 36.4 0.7
24      8 2013/01-2014/01         2       -3.0  Adult    Male 2995 40.4 187.4 37.8 0.7
25      9 2015/01-2016/01         2       -1.0  Adult    Male 2905 40.6 188.0 39.6 0.8
26     10 2017/01-2018/01         2        1.0  Adult    Male 2788 41.0 191.6 41.5 0.8
27     12 2021/08-2023/08         2        5.7  Adult    Male 2931 41.2 189.1 39.6 0.8
28      3 2003/01-2004/01         2      -13.0  Adult Female 3117 42.1 155.3 34.0 0.8
29      4 2005/01-2006/01         2      -11.0  Adult Female 3197 42.5 156.3 36.0 0.8
30      5 2007/01-2008/01         2       -9.0  Adult Female 3097 42.4 157.1 35.1 0.8
31      6 2009/01-2010/01         2       -7.0  Adult Female 3345 42.1 157.7 35.7 0.8
32      7 2011/01-2012/01         2       -5.0  Adult Female 2906 42.4 158.6 35.5 0.8
33      8 2013/01-2014/01         2       -3.0  Adult Female 3217 42.7 160.0 37.3 0.8
34      9 2015/01-2016/01         2       -1.0  Adult Female 3059 42.9 161.7 36.9 0.8
35     10 2017/01-2018/01         2        1.0  Adult Female 2880 43.2 161.9 37.8 0.9
36     12 2021/08-2023/08         2        5.7  Adult Female 3476 42.8 163.0 38.6 0.8
```

The following code and output are newly calculated sample values and adjustments demonstrating application of Part 2 under “Method Definition,” SAPOE 2020. Operators should use adjustments that are most appropriate to their systems.

```
Wx <- left_join(
  Passengers %>% select(cycle,faaAge,gender,W ) %>%
    pivot_wider(names_from=c(faaAge,gender),values_from=W, names_prefix='W_'),
  Passengers %>% select(cycle,faaAge,gender,NP) %>%
    pivot_wider(names_from=c(faaAge,gender),values_from=NP,names_prefix='N_'),
                 by=c('cycle')
      ) %>% rename( N_Infant=N_Infant_None, W_Infant=W_Infant_None )  %>%
  mutate(
    W_Adult_NHANES = F13( N_Adult_Male, N_Adult_Female, W_Adult_Male, W_Adult_Female ),
    W_Adult_5050   = F13(           50,             50, W_Adult_Male, W_Adult_Female ),
    dW_Infant_NHANES = N_Infant / ( N_Adult_Female + N_Adult_Male ) * W_Infant,
    'W_Adult_NHANES+Infant' = W_Adult_NHANES + dW_Infant_NHANES,
    'W_Adult_5050+Infant'   = W_Adult_5050   + dW_Infant_NHANES,
  )
Wx %>% select(cycle, W_Adult_NHANES,W_Adult_5050,dW_Infant_NHANES) %>% fmtWTLB(Cycles2)
Wx %>% select(cycle,'W_Adult_NHANES+Infant','W_Adult_5050+Infant') %>% fmtWTLB(Cycles2)
```

```
  cycle           label duration trendYear W_Adult_NHANES W_Adult_5050 dW_Infant_NHANES
1     3 2003/01-2004/01        2     -13.0          169.8        170.2              0.8
2     4 2005/01-2006/01        2     -11.0          171.3        171.8              0.8
3     5 2007/01-2008/01        2      -9.0          170.7        171.1              0.7
4     6 2009/01-2010/01        2      -7.0          172.5        172.8              0.8
5     7 2011/01-2012/01        2      -5.0          172.0        172.4              0.6
6     8 2013/01-2014/01        2      -3.0          173.3        173.7              0.6
7     9 2015/01-2016/01        2      -1.0          174.5        174.8              0.6
8    10 2017/01-2018/01        2       1.0          176.3        176.7              0.6
9    12 2021/08-2023/08        2       5.7          175.8        176.0              0.6

  cycle           label duration trendYear W_Adult_NHANES+Infant W_Adult_5050+Infant
1     3 2003/01-2004/01        2     -13.0                 170.6               171.0
2     4 2005/01-2006/01        2     -11.0                 172.1               172.6
3     5 2007/01-2008/01        2      -9.0                 171.4               171.9
4     6 2009/01-2010/01        2      -7.0                 173.2               173.6
5     7 2011/01-2012/01        2      -5.0                 172.6               173.0
6     8 2013/01-2014/01        2      -3.0                 174.0               174.4
7     9 2015/01-2016/01        2      -1.0                 175.1               175.4
8    10 2017/01-2018/01        2       1.0                 176.9               177.3
9    12 2021/08-2023/08        2       5.7                 176.3               176.6
```

The following code and output are the survey-derived averages for body mass calculated in accordance with Part 3 under "Method Definition," SAPOE 2020, using two-year cycle data for Male and Female Pilots.

```
Pilots <- subset( WTLB2YR, 23<=RIDAGEYR & 65>RIDAGEYR ) %>% mutate(faaAge='Pilot')
fmtWTLB( sapoeNHANES( Pilots ), Cycles2 )
```

```
   cycle           label duration trendYear faaAge gender    n   NP     W    S te%
1      3 2003/01-2004/01        2     -13.0  Pilot   Male 1321 48.6 190.6 32.1 0.9
2      4 2005/01-2006/01        2     -11.0  Pilot   Male 1444 48.8 194.2 35.5 0.9
3      5 2007/01-2008/01        2      -9.0  Pilot   Male 1776 49.3 191.2 34.4 0.8
4      6 2009/01-2010/01        2      -7.0  Pilot   Male 1873 48.8 194.8 36.5 0.8
5      7 2011/01-2012/01        2      -5.0  Pilot   Male 1714 49.0 192.5 34.9 0.9
6      8 2013/01-2014/01        2      -3.0  Pilot   Male 1795 49.3 193.7 35.4 0.8
7      9 2015/01-2016/01        2      -1.0  Pilot   Male 1705 49.1 193.6 38.0 0.9
8     10 2017/01-2018/01        2       1.0  Pilot   Male 1585 49.0 199.0 41.0 1.0
9     12 2021/08-2023/08        2       5.7  Pilot   Male 1565 49.3 195.8 38.6 1.0
10     3 2003/01-2004/01        2     -13.0  Pilot Female 1489 51.4 161.2 35.7 1.1
11     4 2005/01-2006/01        2     -11.0  Pilot Female 1649 51.2 163.1 37.4 1.1
12     5 2007/01-2008/01        2      -9.0  Pilot Female 1850 50.7 162.9 35.7 1.0
13     6 2009/01-2010/01        2      -7.0  Pilot Female 2045 51.2 162.8 36.8 1.0
14     7 2011/01-2012/01        2      -5.0  Pilot Female 1783 51.0 164.3 35.1 1.0
15     8 2013/01-2014/01        2      -3.0  Pilot Female 1923 50.7 167.0 39.1 1.0
16     9 2015/01-2016/01        2      -1.0  Pilot Female 1886 50.9 167.3 38.4 1.0
17    10 2017/01-2018/01        2       1.0  Pilot Female 1744 51.0 166.9 39.2 1.1
18    12 2021/08-2023/08        2       5.7  Pilot Female 1979 50.7 171.0 41.0 1.1
```

The following code and output are newly calculated sample values for several M_P:F_P ratios, demonstrating application of Part 3 under "Method Definition," SAPOE 2020, using two-year cycle data for Pilots.

```
fmtWTLB( sapoeNHANES( Pilots ) %>% select(cycle,gender,W)                      %>%
           pivot_wider(names_from=c(gender),values_from=W,names_prefix='W_P__') %>%
           mutate( W_P_50=F13( 50,50, W_P__Male,W_P__Female ),
                   W_P_99=F13( 99, 1, W_P__Male,W_P__Female )) , Cycles2 )
```

```
  cycle           label duration trendYear W_P__Male W_P__Female W_P_50 W_P_99
1     3 2003/01-2004/01        2     -13.0     190.6       161.2  175.9  190.3
2     4 2005/01-2006/01        2     -11.0     194.2       163.1  178.6  193.9
3     5 2007/01-2008/01        2      -9.0     191.2       162.9  177.0  190.9
4     6 2009/01-2010/01        2      -7.0     194.8       162.8  178.8  194.4
5     7 2011/01-2012/01        2      -5.0     192.5       164.3  178.4  192.2
6     8 2013/01-2014/01        2      -3.0     193.7       167.0  180.4  193.4
7     9 2015/01-2016/01        2      -1.0     193.6       167.3  180.4  193.3
8    10 2017/01-2018/01        2       1.0     199.0       166.9  182.9  198.6
9    12 2021/08-2023/08        2       5.7     195.8       171.0  183.4  195.6
```

The following code and output are the survey-derived averages for body mass calculated in accordance with Part 3 under "Method Definition," SAPOE 2020, using two-year cycle data for Male and Female Flight Attendants (F/A).

```
FlightAttendants <- filter( WTLB2YR, 21<=RIDAGEYR ) %>% mutate(faaAge='F/A')
fmtWTLB( sapoeNHANES( FlightAttendants ), Cycles2 )
```

```
   cycle           label duration trendYear faaAge gender    n   NP     W    S te%
1      3 2003/01-2004/01        2     -13.0    F/A   Male 2030 48.3 189.2 33.1 0.8
2      4 2005/01-2006/01        2     -11.0    F/A   Male 2048 48.0 192.2 35.3 0.8
3      5 2007/01-2008/01        2      -9.0    F/A   Male 2503 48.1 190.0 34.6 0.7
4      6 2009/01-2010/01        2      -7.0    F/A   Male 2634 48.4 192.4 36.5 0.7
5      7 2011/01-2012/01        2      -5.0    F/A   Male 2327 48.5 190.4 34.5 0.7
6      8 2013/01-2014/01        2      -3.0    F/A   Male 2404 48.3 191.7 35.5 0.7
7      9 2015/01-2016/01        2      -1.0    F/A   Male 2338 48.3 192.5 37.5 0.8
8     10 2017/01-2018/01        2       1.0    F/A   Male 2292 48.4 196.6 40.1 0.8
9     12 2021/08-2023/08        2       5.7    F/A   Male 2461 48.5 193.3 37.8 0.8
10     3 2003/01-2004/01        2     -13.0    F/A Female 2173 51.7 158.7 33.9 0.9
11     4 2005/01-2006/01        2     -11.0    F/A Female 2228 52.0 160.1 36.2 0.9
12     5 2007/01-2008/01        2      -9.0    F/A Female 2602 51.9 160.3 34.6 0.8
13     6 2009/01-2010/01        2      -7.0    F/A Female 2803 51.6 161.1 36.1 0.8
14     7 2011/01-2012/01        2      -5.0    F/A Female 2378 51.5 161.9 34.8 0.9
15     8 2013/01-2014/01        2      -3.0    F/A Female 2597 51.7 163.2 36.5 0.9
16     9 2015/01-2016/01        2      -1.0    F/A Female 2524 51.7 164.2 36.4 0.9
17    10 2017/01-2018/01        2       1.0    F/A Female 2405 51.6 165.1 37.6 0.9
18    12 2021/08-2023/08        2       5.7    F/A Female 3010 51.5 166.4 38.3 0.8
```

The following code and output are newly calculated sample values for several M_{FA}:F_{FA} ratios, demonstrating application of Part 3 under "Method Definition," SAPOE 2020, using two-year cycle data for Flight Attendants.

```
fmtWTLB( sapoeNHANES( FlightAttendants ) %>% select(cycle,gender,W)         %>%
  pivot_wider(names_from=c(gender),values_from=W,names_prefix='W_FA_')      %>%
  mutate( W_FA_50=F13( 50,50, W_FA_Male,W_FA_Female ),
          W_FA_99=F13( 99, 1, W_FA_Male,W_FA_Female )) , Cycles2 )
```

```
  cycle           label duration trendYear W_FA_Male W_FA_Female W_FA_50 W_FA_99
1     3 2003/01-2004/01        2     -13.0     189.2       158.7   174.0   188.9
2     4 2005/01-2006/01        2     -11.0     192.2       160.1   176.2   191.9
3     5 2007/01-2008/01        2      -9.0     190.0       160.3   175.2   189.7
4     6 2009/01-2010/01        2      -7.0     192.4       161.1   176.8   192.1
5     7 2011/01-2012/01        2      -5.0     190.4       161.9   176.2   190.1
6     8 2013/01-2014/01        2      -3.0     191.7       163.2   177.4   191.4
7     9 2015/01-2016/01        2      -1.0     192.5       164.2   178.4   192.3
8    10 2017/01-2018/01        2       1.0     196.6       165.1   180.9   196.3
```

```
   9    12 2021/08-2023/08         2        5.7      193.3        166.4    179.8    193.0
```

The output above includes all NHANES data points used in the analysis that follows.

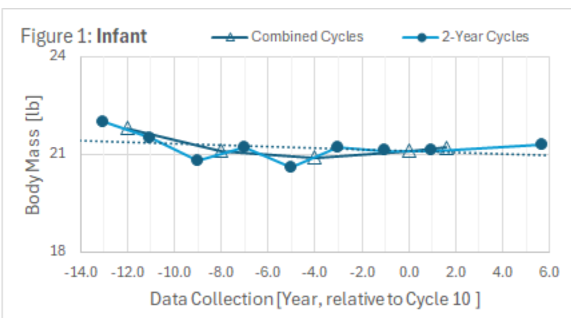
ANALYSIS AND DISCUSSION

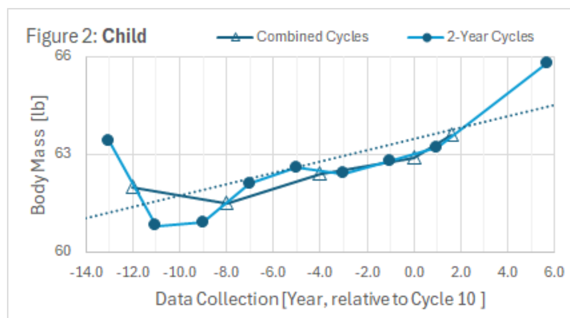
The most significant change from SAPOE 2020 to SAPOE 2024 is the use of two-year cycle 12 after Covid while combined cycles were used prior to Covid. Each is consistent with Analytic Guidelines, but the difference merits examination.

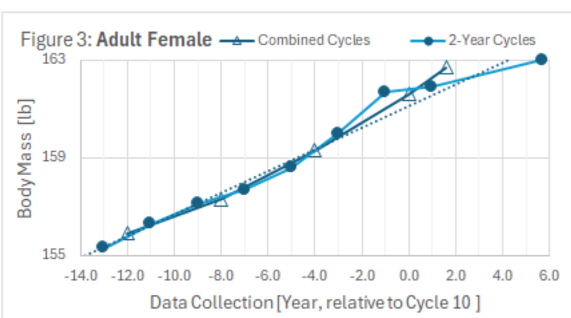
To compare these, Figure 1 through Figure 4 below plot the average values computed using two-year cycle data and those computed using combined cycles, against the relative time scale defined above as `trendYear`. For visual reference only, the dotted line in each Figure is a least-squares trend line for the set of average values using two-year cycles, beginning with cycle 3 and including cycles 10 and 12.

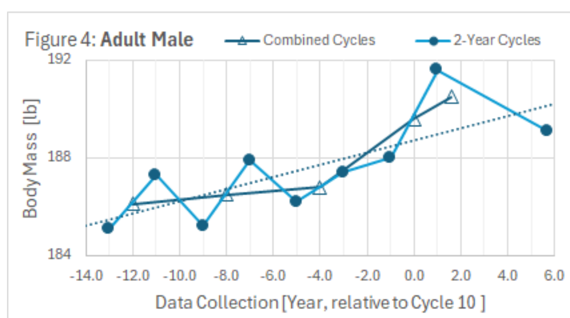
There is significantly more variation between average values from the two-year cycles than from the combined cycles. In every category, the combined-cycle values are consistent with the depicted trend. Most of the values from the combined cycles are closer to the trend line calculated from the two-year cycle values than the two-year values themselves. This makes it clear that the most significant effect of using combined cycles was to reduce variation between cycles. Returning to the use of combined cycles may have similar value if Analytic Guidelines in the future defines an appropriate method of combining data post-Covid, as it does for combining pre-Covid data.

Survey-Derived Average Values for Body Mass of Passengers by Category









Finally, despite an overall increasing trend, the average value for Adult Male decreased from cycle 10 to cycle 12. Since in three of the four categories the average value has changed in the opposite direction of the overall trend multiple times in the past, this decrease is consistent with past variation and does not itself suggest an error.

UPDATED SUMMARY VALUES

The following tables summarize results found under "Method Definition," SAPOE 2020, applied to NHANES combined cycles from 2003 to 2018 and the two-year cycle for August 2021–August 2023.

Table 2024-3: Survey-Derived Average Passenger Weights from NHANES Data (LB)

NHANES Cycle	Adult Male			Adult Female			Child			Infant		
	n_f	W_M	σ	n_f	W_F	σ	n_f	W_C	σ	n_f	W_I	σ
2003-2006	5940	186.1	36.1	6321	155.9	35.1	4087	62.0	26.4	1494	21.8	5.1
2007-2010	6291	186.5	37.3	6435	157.3	35.3	4156	61.5	26.7	1382	21.1	4.9
2011-2014	5879	186.8	37.1	6125	159.3	36.4	4303	62.4	29.9	1167	20.9	5.2
2015-2018	5689	189.6	40.5	5937	161.6	37.2	3692	62.9	26.3	1118	21.1	5.0
2021/08-2023/08	2931	189.1	39.6	3476	163.0	38.6	1439	65.8	29.1	230	21.3	4.5

Table 2024-4: Survey-Derived Average Crewmember Weights from NHANES Data (LB)

NHANES Cycle	Pilot, Male			Pilot, Female			Flight Attendant, Male			Flight Attendant, Female		
	n_f	$W_{P,M}$	σ	n_f	$W_{P,F}$	σ	n_f	$W_{FA,M}$	σ	n_f	$W_{FA,F}$	σ
2003-2006	2766	192.5	33.8	3136	162.1	36.5	4080	190.6	34.2	4400	159.3	35.0
2007-2010	3650	193.0	35.5	3893	162.8	36.2	5133	191.3	35.6	5403	160.6	35.2
2011-2014	3513	193.1	35.1	3709	165.9	37.4	4724	191.1	35.0	4986	162.8	35.9
2015-2018	3288	196.2	39.5	3631	167.2	38.9	4626	194.5	38.7	4928	164.7	37.1
2021/08-2023/08	1565	195.8	38.6	1979	171.0	41.0	2461	193.3	37.8	3010	166.4	38.3

Table 2024-5: Adjusted Body Weights for Sample M:F Ratios (LB)

NHANES Cycle	[W_X] Not Adjusted for Infants						[W_X] Adjusted for Infants	
	Pilots		Flight Attendants		Adults	Adults	Adults	Adults
M:F	50:50	99:1	50:50	99:1	NHANES	50:50	NHANES	50:50
2003-2006	177.3	192.2	175.0	190.3	170.5	171.0	171.3	171.7
2007-2010	177.9	192.7	175.9	190.9	171.6	171.9	172.3	172.7
2011-2014	179.5	192.8	176.9	190.8	172.7	173.0	173.3	173.6
2015-2018	181.7	195.9	179.6	194.2	175.3	175.6	175.9	176.2
2021/08-2023/08	183.4	195.6	179.8	193.0	175.8	176.0	176.3	176.6

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APPENDIX A: CONSIDERING THE FUTURE

In many operational planning and design contexts, it would be useful to forecast the survey-derived average for body mass in effect at some future date. The value in effect is typically the most recently published value at the time in question. It may not be the value that will be determined in analysis following completion of the data-collection period ongoing at the time in question, especially since that value cannot yet be known while data collection is not yet complete. (At the planned midpoint of the cycle 11 data-collection period, in January 2020, it was not yet known that the cycle would not be completed.) However, it is reasonable to expect that the survey-derived average for body mass in effect might grow at the same rate as the average for body mass calculated according to the method used above. In other words, a useful forecast might be a solution to a differential equation describing the empirical data, but from a distinct initial condition.

In Figure 1 through Figure 4 above, it appears upon inspection that a simple constant slope is a good model for growth for each passenger category over time, despite short-term variation. Logically, body mass cannot grow in perpetuity, so future analysis should look for an eventual change in growth rate. However, as noted above, in each category the change from cycle 10 to cycle 12 is consistent with past variation, so no change in derivative beyond past variation is evident yet. Using this model, all forecasts have the simple form:

$$S = \frac{dW}{dT} \qquad (2024\text{-}1)$$

where S is a constant growth rate determined from past data, and thus:

$$W = W_0 + S \cdot (T - T_0). \qquad (2024\text{-}2)$$

The choice of initial condition (T_0, W_0) is of interest.

It is common to simplify forecasting by using a single effective passenger weight, called $[W_X]$ in SAPOE 2020. Such a simplified model is obtained by assuming all passengers are 50:50 Adults and differentiating Formula (2020-12) to obtain:

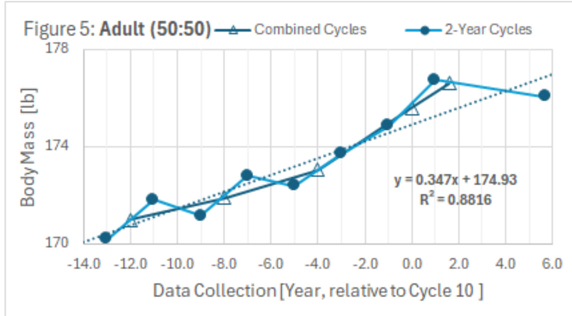
$$[W_X] = \tfrac{1}{2}(W_M + W_F) \qquad (2020\text{-}12)$$

$$S = \frac{d}{dT}[W_X] = \tfrac{1}{2}\left(\frac{dW_M}{dT} + \frac{dW_F}{dT}\right). \qquad (2024\text{-}3)$$

Values for dW_M/dT and dW_F/dT can be determined separately for Male and Female body mass from Figure 3 and Figure 4 above, respectively, or from $[W_X]$ directly as shown in Figure 5. As above, the dotted line in Figure 5 is a least-squares trend line for the set of average values computed using two-year cycles, beginning with cycle 3 and including cycles 10 and 12. The equation depicted in Figure 5 is not the final proposed forecast model, but does show:

$$S = 0.347\ lb/year \qquad (2024\text{-}4)$$

(The precision for S is limited by body-mass precision and by rounding dates to tenths of a year.)



Alternatively, the value of S could be determined by differentiating Formula (2020-10) or Formula (2020-11), instead of Formula (2020-12), and applying operator-specific data for N_I, N_C, N_F, N_M, and N_A defined in those formulas. If separate forecast models are needed for Infant and Child passengers, a separate value for S could also be determined from Figure 2 above and used in the same way as demonstrated here. For Infants, Figure 1 above suggests assuming a derivative of zero, or a constant value of 21 lb.

The initial condition might be selected from any published survey-derived average for body mass. The most relevant cases are averages based on NHANES data, for which the authors have reconstructed the following history.

1. The first known publication of passenger weights based on NHANES is FAA AC 120-27D, dated August 11, 2004. This gave a “Summer Passenger” value of 190 lb, summer clothing weight of 5 lb, and carry-on allowance of 16 lb, implying a body mass of 169 lb for $[W_X]$. (The “Winter Passenger” was 5 lb heavier due to assumed winter clothing of 10 lb, giving the same body mass.)
2. FAA AC 120-27E was published June 11, 2005, with the same values as AC 120-27D.
3. Correspondence shared with the authors, dated July 2006, shows an analysis of the 2003–2004 cycle data and a comparison to past analysis of the 1999–2000 cycle data. Both analyses appear to be consistent with the SAPOE 2020 method, but the authors have not found any publication of these results.
4. Since AC 120-27F was published without values, the next known published values are in SAPOE 2020, which gave $[W_X]$ value for a 50:50 Adult of 175.6 lb. The late 2020 publication date rounds to 2021.0.
5. The calculations above in this paper show the most recent $[W_X]$ value for a 50:50 Adult of 176.0 lb, which is labelled “SAPOE 2024.” The late 2024 publication date rounds to 2025.0.
6. In accordance with AC 120-27F, it is anticipated that the SAPOE 2024 value will remain in effect for at least 36 months after it is published.

This history is visualized in the following table and plot. Like in Figure 1 through Figure 5, the horizontal axis time values used are continuous decimal years relative to a recent date. The reference date is chosen for convenience as the publication of SAPOE 2020, when NHANES cycle 2015–2018 was the most recently available combined cycle.

Initial Condition	T_0	Relative Year	W_0
AC 120-27D (August)	2004.6	-16.3	169.0
AC 120-27E (June)	2005.4	-15.5	169.0
SAPOE 2020 (December)	2021.0	0.0	175.6
SAPOE 2024 (December)	2025.0	4.0	176.0
SAPOE 2024 +36 months	2028.0	7.0	176.0

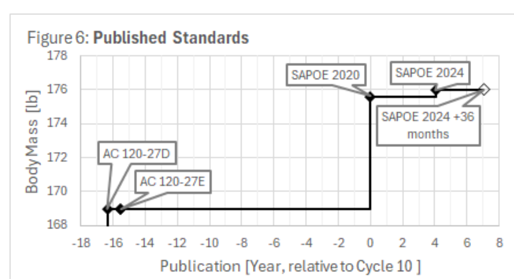


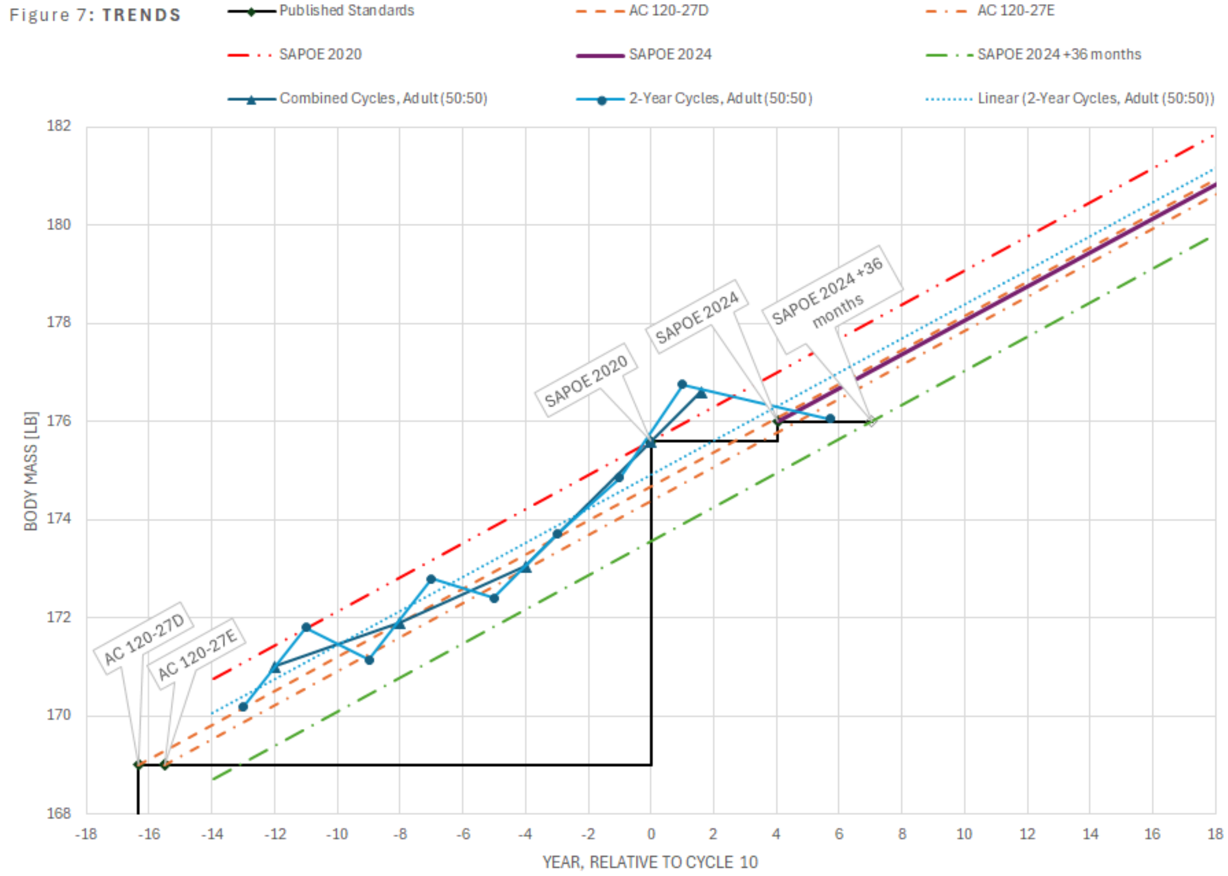
Figure 7 shows forecast models defined by Formula (2024-2) for each of the initial conditions considered. In addition, two-year cycle average values from Figure 5 are plotted on the same relative time scale, effectively comparing the most recently available data to the published values.

Comparing forecast models for the oldest and newest initial conditions highlights the consistency of these models over the entire duration of NHANES use. The model projected forward from the most recent initial condition is from SAPOE 2024 (shown in solid purple). The forward projection from the oldest initial condition, AC 120-27D (shown in orange short dashes), differs by less than 0.1 lb. The forward projection from initial condition AC 120-27E (shown in orange short-dash-dots) is just 0.2 lb lower.

The trend line from the overlay of two-year cycle data (shown in blue dots) is parallel to the model, due to the model definition, and is just 0.2 lb higher than the forecast from SAPOE 2024.

The highest forecast model (shown in red long-dash-double-dots) is from SAPOE 2020 and is 1.0 lb higher than from SAPOE 2024. The lowest forecast model (shown in green long-dash-dots) is from the anticipated effectivity of SAPOE 2024 for 36 months after publication and is 1.0 lb lower. Together these bound the variation from all but one average value from each set of data cycles, providing a convenient, if coarse, estimate of future variation.

Figure 7: **TRENDS**



Balancing the possibilities evaluated, the most reasonable forecast is thus from the initial condition in SAPOE 2024:

$$[W_X] = 176.0\ lb + 0.347\frac{lb}{year} \cdot (T - 2025.0) \pm 1.0\ lb \qquad (2024\text{-}5)$$

Care must be taken to evaluate the assumptions made in defining this forecast and whether these are applicable to any scenario to which the forecast is applied. Such a decision, and its outcome, is strictly the responsibility of the individual who applies it.

No attempt has been made here to determine how far into the future this forecast might be useful.

It is hoped that this forecast has value for the design of airplanes and components intended for future use. In addition, this forecast might be useful if future NHANES data collection or analysis is disrupted or delayed, or to reduce the effect of the greater variation seen when using two-year cycles compared to past use of combined cycles.

APPENDIX B: UPDATED SAMPLE CODE

Running this script requires the R language core, which is freely available for a variety of platforms from [www.r-project.org]. Use is simplified by a graphical interface, such as RStudio Desktop (available as of this writing at no cost from [rstudio.com]). Packages required for installation are `dplyr`, `foreign`, `survey`, and `tidyr`.

A small font and large page are used to assist copying and pasting from this document into plain text.

```r
#==============================================================================
# Script for 'CONTINUED NHANES USE FOR STANDARD AVERAGE BODY WEIGHT'
#  (c) 2024 Society of Aircraft Performance and Operations Engineers (SAPOE)
# Modified from code included in 'NHANES USE FOR STANDARD AVERAGE BODY WEIGHT'
#  (c) 2020 Society of Aircraft Performance and Operations Engineers (SAPOE)
#
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#  flight through knowledge of aircraft performance and weight and balance
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#  no warranty of any kind. Anyone who uses this report, or the source code
#  and data contained in it, is solely responsible for their own operations
#  and for any outcome of such use.

#------------------------------------------------------------------------------
# These libraries need to be installed, along with the base R language

# The 'dplyr' library simplifies and improves readability, especially with
#  'bind_rows()' to append rows of data to an existing data frame,
#  'mutate()' to add calculated columns to an existing data frame,
#  'group_by()' to define categories within the data, and
#  'summarise()' [note spelling] to calculate summary statistics
library(dplyr)

# The 'tidyr' library simplifies and improves readability with
#  pivot() and pivot_wider() for combining and summarizing data tables
library(tidyr)

# The 'foreign' library reads SAS Transport(XPT) files
library(foreign)

# The 'survey' library allows use of multi-stage survey design parameters
# to calculate weighted mean and standard error estimates recommended by
# Analytic Guidelines and NHANES tutorials
library(survey)

#------------------------------------------------------------------------------
# Define a helper to keep all the meta data defining each cycle consistent
#  This must be updated after cycle 12 for future NHANES conventions.
nhanesCycleDefinitions <- function( combine )
{
  # NHANES defined values for all the cycles with consistent data definitions
  #  66 is a pre-covid set combining cycle 10 and the discontinued cycle 11
  allCycles = c(3:10,66,12)

  if( !combine ) # use cycles as-is, except exclude the pre-covid combined set
  {
    cN <- allCycles[ allCycles != 66 ]  # exclude the 3.2-year pre-covid cycle
    cL <- rep( 2, length(cN) )          # all remaining cycles are two years
    dataMod <- function(df)
    {
      filter( df, 66 != SDDSRVYR ) %>%  # remove all data from excluded cycles
      mutate(
        cycle = SDDSRVYR,               # don't combine cycle numbers
        svyWt = WTMEC2YR                # don't combine design parameters
      )
    }
  } else            # combine cycles only as recommended in Analytic Guidelines
  {
    cN <- c(4,6,8,10,66)                # even pairs pre-covid (TBD post-covid)
    cL <- ifelse( 66 == cN, 3.2, 4 )    # each pair is four years, except 66
    dataMod <- function(df)
    {
      filter( df, 12 != SDDSRVYR ) %>%  # remove all data from excluded cycles
      mutate(                           # combine data cycles as recommended
        cycle = ifelse( 66 == SDDSRVYR, 66, 2*ceiling(SDDSRVYR/2) ),
        svyWt = ifelse( 66 == SDDSRVYR, WTMECPRP, WTMEC2YR/2 )
      )
    }
  }

  cE <- 2000+2*(cN-1) # a nominal end year, used below
  cS <- ifelse( 10 >= cN, sprintf('%i/01-%i/01'    ,cE-ceiling(cL-1),cE),
        ifelse( 66 == cN ,          '2017/01-2020/03',
        ifelse( 12 == cN,           '2021/08-2023/08',
                                    'Undefined Cycle'
        )))

#  Cycle periods are no longer constant, so trend analysis vs. time must be
#   adjusted to reflect variation in both the start and duration of the data
#   collection. CDC uses the midpoint in decimal years. See References
#   '... Analytic Guidelines for NHANES August 2021-August 2023'
#   and https://www.cdc.gov/nchs/data/series/sr_02/sr02-190.pdf
  cY <- ifelse( 10 >= cN, cE - floor((cL-1)/2), # x.0 for older cycles
        ifelse( 66 == cN, 2018.6, # Mid-July 2018 for Jan 2017 to Mar 2020
        ifelse( 12 == cN, 2022.7, # August   2022 for Aug 2021 to Aug 2023
                          NaN     # a numeric value for 'Not Defined'
        )))

# To compare to publications, SAPOE uses CDC recommended time, but relative to
#  the last 4-year cycle when the Dec 2020 paper was published, "2015-2018".
  tY <- cY - cY[cN==10]      # relative to Cycle 10
  if( !combine ) tY <- tY+1 # the combined cycle centers 1 year earlier

  list( combined = combine, dataModifier = dataMod,
        metaData = data.frame( cycle=cN, label=cS, duration=cL, trendYear=tY )
      )
}

#------------------------------------------------------------------------------
# Define a helper to keep all the source files download/import consistent
#  Files naming is superficially like cycle numbering, but differs slightly
#  since cycle 10 and may vary in the future independently of survey design.
importRawDataFiles <- function( cN ) # raw data cycles to import
{
  # the urls all follow a pattern, except for the combined pre-covid cycle
  y <- ifelse( 66 == cN, 2018, 2000+2*(cN-1) )
  p <- sprintf('https://wwwn.cdc.gov/nchs/nhanes/%s-%s/',y-1,y)
  D <- ifelse( 66 == cN, 'P_DEMO.XPT', sprintf('DEMO_%s.XPT',LETTERS[cN]) )
  B <- ifelse( 66 == cN, 'P_BMX.XPT' , sprintf( 'BMX_%s.XPT',LETTERS[cN]) )

  allData <- data.frame(NULL)
  for(i in 1:length(cN))
  {
    # download the files only if they don't already exist
    if( !file.exists(D[i]) ) download.file( paste0(p[i],D[i]), D[i], mode='wb' )

    demo <- select( read.xport(D[i]),
      # only needed columns from the DEMO file here
      any_of(c('SEQN','SDDSRVYR','RIDAGEYR','RIAGENDR','RIDEXPRG',
               'SDMVSTRA','SDMVPSU','WTMEC2YR','WTMECPRP'))
    )
    # add missing columns so all cycles have the same columns
    if( is.na(match('WTMEC2YR',names(demo))) ) demo <- mutate(demo,WTMEC2YR=NA)
    if( is.na(match('WTMECPRP',names(demo))) ) demo <- mutate(demo,WTMECPRP=NA)

    # exclude participants without an exam record before joining
    demo <- subset( demo, !(is.na(WTMEC2YR) & is.na(WTMECPRP)) )

    # download the files only if they don't already exist
    if( !file.exists(B[i]) ) download.file( paste0(p[i],B[i]), B[i], mode='wb' )

    bmx <- select( read.xport(B[i]),
      # only needed columns from the BMX file here
      c('SEQN','BMXWT','BMIWT')
    )

    allData <- bind_rows(allData,left_join( demo, bmx, by = 'SEQN' ))
  }
  return(allData)
}

#------------------------------------------------------------------------------
# Create a copy with calculated columns added (preserve RawData)
#  Don't remove or delete any rows or survey design parameters are lost.
enrichDataSet <- function( rawData, cycleDefs )
{
  richData <- mutate(rawData,
    # 'one' is needed to count records
    one    = 1,

    # make it easy to work in US units
    WTLB   = BMXWT / 0.45359237, # kg to lb

    # use cut(right=FALSE) to build age intervals that include the lower
    #  and exclude the upper boundary
    #
    # for FAA, Infants have not yet reached 2nd birthday.
    #         Children have not yet reached 13th birthday.
    faaAge = cut(RIDAGEYR, breaks=c(-Inf,       2,      13,     Inf),
             right=FALSE, labels=c(      'Infant', 'Child', 'Adult')),
    gender=factor(ifelse(RIDAGEYR>12,RIAGENDR,0),labels=c('None','Male','Female')),
    #
    # for comparison to CDC/NHSR, Adults are age 20 and over
    cdcAge = cut(RIDAGEYR, breaks=c(-Inf,      20,     Inf),
             right=FALSE, labels=c(      'Child', 'Adult')),

    # columns used to "filter" the data, like 'inAnalysis' in tutorials
    #  NOTE: use subset(), not filter(), to "filter" or design parameters are lost
    NotMissing  = ( !is.na(BMXWT) ),
    NotClothed  = ( NotMissing & (is.na(BMIWT)    | 3!=BMIWT) ),
    NotPregnant = ( NotMissing & (is.na(RIDEXPRG) | 1!=RIDEXPRG) )
    # for RIDEXPRG, 1=Yes, 2=No, 3=Unknown, Missing => No
  )

  cycleDefs$dataModifier( richData ) %>% subset( NotMissing )
}

#------------------------------------------------------------------------------
# Define a function to get the weighted mean and standard error estimate
#  using survey design parameters and join to the unweighted count.
#  Based heavily on https://wwwn.cdc.gov/nchs/nhanes/tutorials/samplecode.aspx
#  and https://wwwn.cdc.gov/nchs/data/tutorials/DB303_Fig1_R.R,
#  this is unmodified from 2020 and not likely to change in the future.
svyWTLB <- function(design, byFormula)
{
  # Get mean, stderr, and unweighted sample size
  c <- svyby( ~WTLB, byFormula, design, unwtd.count )
  p <- svyby( ~WTLB, byFormula, design, svymean )
  # select(c,-se) excludes the standard error of the count
  # suppressMessages() just hides output of the implicit "by" columns
  suppressMessages( outData <- left_join(select(c,-se), p) )
  return(outData)
}

#------------------------------------------------------------------------------
# Define a function to get consistent output formatting
fmtWTLB <- function( results, cycleDefs )
{
  T <- right_join( cycleDefs$metaData, results, by='cycle' )

  sorts <- c('cycle')
  if( !is.na(match( 'cdcAge' ,names(T))) ) sorts <- c('cdcAge',sorts)
  if( !is.na(match( 'faaAge' ,names(T))) ) sorts <- c('faaAge',sorts)
  if( !is.na(match( 'gender' ,names(T))) ) sorts <- c('gender',sorts)

  mutate_if(T %>% arrange_at(sorts) , is.numeric,round,digits=1)
}

#------------------------------------------------------------------------------
# Define a function to do exactly the METHOD defined in SAPOE's 2020 paper.
sapoeNHANES <- function( allData )
{
  # A copy of the data excluding clothed sample participants
  Step0 <- allData %>% filter(NotClothed)

  # Calculate a raw weighted mean, w-bar-star (ws) using Formula (2020-1)
  Step1 <- mutate(Step0, ww=WTLB*svyWt)                                   %>%
    summarise( ws=sum(ww)/sum(svyWt), .by=c(faaAge,gender,cycle) )

  # Sum weighted residuals (wr) for each row to get sigma-star (ss) using Formula (2020-2)
  Step2 <- left_join(Step0,Step1,by=c('faaAge','gender','cycle'))         %>%
    mutate( wr=svyWt*(WTLB-ws)^2 )                                        %>%
    summarise( n=sum(one), ss=sqrt(sum(wr)/((n-1)/n*sum(svyWt))),
               .by=c(faaAge,gender,cycle,ws) )

  # fmtWTLB(Step2 %>% select(cycle,faaAge,gender,n,ws,ss,'te%')) # for debugging

  # Filter by excluding values more than twice ss from the raw mean
  Step3 <- left_join(Step0,Step2,by=c('faaAge','gender','cycle'))         %>%
    filter( 2 >= abs((WTLB-ws)/ss) )

  # Calculate population totals, after filter, for use in Formula (2020-7)
  NN <- Step3 %>% summarise( Nt=sum(svyWt), .by=cycle )

  # Calculate a weighted mean, W using Formula (3) and then Formula (2020-7)
  Step4 <- mutate(Step3, wr=WTLB*svyWt)                                   %>%
    summarise( W=sum(wr)/sum(svyWt), Nc=sum(svyWt),
               .by=c(faaAge,gender,cycle) )                               %>%
    left_join(NN,by='cycle') %>% summarise( NP=100*Nc/Nt,
                                    .by=c(faaAge,gender,cycle,W) )

  # Sum weighted residuals (wr) for each row to get sigma (S) using Formula (2020-4)
  Step5 <- left_join(Step3,Step4,by=c('faaAge','gender','cycle'))         %>%
    mutate( wr=svyWt*(WTLB-W)^2 )                                         %>%
    summarise( n=sum(one), S=sqrt(sum(wr)/((n-1)/n*sum(svyWt))),
               .by=c(faaAge,gender,cycle,W,NP) )                          %>%
    mutate( 'te%'=196*S/W/sqrt(n) )

  Step5 %>% select(cycle,faaAge,gender,n,NP,W,S,'te%')
}

#------------------------------------------------------------------------------
# apply sample M:F ratios using Formula (2020-13)
F13 <- function(M,F,W_M,W_F) { ( M*W_M + F*W_F )/(M+F) }

#------------------------------------------------------------------------------
#
# set the working directory to where the raw data is or will be saved
setwd( 'C:/NHANES/' )

RawData <- importRawDataFiles(c(3:10,66,12))

Cycles2 <- nhanesCycleDefinitions(FALSE)
WTLB2YR <- enrichDataSet( RawData, Cycles2 )

# Define survey design parameters for overall dataset, per NHANES Tutorials
NHANES2<-svydesign(data=WTLB2YR, id=~SDMVPSU, strata=~SDMVSTRA, weights=~svyWt, nest=TRUE)

# confirm definitions above here are correct for full NHANES by comparing to
#  https://www.cdc.gov/nchs/data/nhsr/nhsr122-508.pdf
 svyWTLB( subset( NHANES2, NotPregnant ), ~cycle+cdcAge+gender ) %>% fmtWTLB(Cycles2) %>%
  filter( cdcAge=='Adult' & cycle<10 ) # NHSR Table 2 has Adults in these years

#------------------------------------------------------------------------------
# confirm definitions above here are correct for FAA/SAPOE definitions by calculating
#  weights for past cycles and comparing output calculations shown in 2020.

Cycles4 <- nhanesCycleDefinitions(TRUE )
WTLB4YR <- enrichDataSet( RawData, Cycles4 )

Passengers <- sapoeNHANES( WTLB4YR )
fmtWTLB( Passengers, Cycles4 )

#------------------------------------------------------------------------------
# Then use the same process to recalculate averages from 2-year cycles

Passengers <- sapoeNHANES( WTLB2YR )
fmtWTLB( Passengers, Cycles2 )

Wx <- left_join(
  Passengers %>% select(cycle,faaAge,gender,W ) %>%
    pivot_wider(names_from=c(faaAge,gender),values_from=W, names_prefix='W_'),
  Passengers %>% select(cycle,faaAge,gender,NR) %>%
    pivot_wider(names_from=c(faaAge,gender),values_from=NR,names_prefix='N_'),
               by=c('cycle')
      ) %>% rename( N_Infant=N_Infant_None, W_Infant=W_Infant_None )  %>%
  mutate(
    W_Adult_NHANES = F13( N_Adult_Male, N_Adult_Female, W_Adult_Male, W_Adult_Female ),
    W_Adult_5050   = F13(           50,             50, W_Adult_Male, W_Adult_Female ),
    dW_Infant_NHANES = N_Infant / ( N_Adult_Female + N_Adult_Male ) * W_Infant,
    'W_Adult_NHANES+Infant' = W_Adult_NHANES + dW_Infant_NHANES,
    'W_Adult_5050+Infant'   = W_Adult_5050   + dW_Infant_NHANES,
  )
Wx %>% select(cycle, W_Adult_NHANES,W_Adult_5050,dW_Infant_NHANES) %>% fmtWTLB(Cycles2)
Wx %>% select(cycle,'W_Adult_NHANES+Infant','W_Adult_5050+Infant') %>% fmtWTLB(Cycles2)

#------------------------------------------------------------------------------

# Pilots <- subset( WTLB4YR, 23<=RIDAGEYR & 65>RIDAGEYR ) %>% mutate(faaAge='Pilot')
# fmtWTLB( sapoeNHANES( Pilots ), Cycles4 )

Pilots <- subset( WTLB2YR, 23<=RIDAGEYR & 65>RIDAGEYR ) %>% mutate(faaAge='Pilot')
fmtWTLB( sapoeNHANES( Pilots ), Cycles2 )

fmtWTLB( sapoeNHANES( Pilots ) %>% select(cycle,gender,W)                  %>%
           pivot_wider(names_from=c(gender),values_from=W,names_prefix='W_P__') %>%
           mutate( W_P_50=F13( 50,50, W_P__Male,W_P__Female ),
                   W_P_99=F13( 99, 1, W_P__Male,W_P__Female )) , Cycles2 )

#------------------------------------------------------------------------------

# FlightAttendants <- filter( WTLB4YR, 21<=RIDAGEYR ) %>% mutate(faaAge='F/A')
# fmtWTLB( sapoeNHANES(  FlightAttendants ), Cycles4 )

FlightAttendants <- filter( WTLB2YR, 21<=RIDAGEYR ) %>% mutate(faaAge='F/A')
fmtWTLB( sapoeNHANES( FlightAttendants ), Cycles2 )

fmtWTLB( sapoeNHANES( FlightAttendants ) %>% select(cycle,gender,W)        %>%
  pivot_wider(names_from=c(gender),values_from=W,names_prefix='W_FA_')     %>%
  mutate( W_FA_50=F13( 50,50, W_FA_Male,W_FA_Female ),
          W_FA_99=F13( 99, 1, W_FA_Male,W_FA_Female )) , Cycles2 )

#==============================================================================
```

APPENDIX C: SAPOE 2020 (Reprint)

A reprint of the complete reference 'SAPOE 2020' follows this final page.

NHANES USE FOR STANDARD AVERAGE BODY WEIGHT

14 DEC 2020

ABSTRACT

For use in aircraft weight and balance, a method to determine standard average weights for body mass of passengers and crew is defined. The method uses data from the US Centers for Disease Control (CDC) National Health and Nutrition Examination Survey (NHANES) in a manner consistent with guidance from the Federal Aviation Administration (FAA), especially Advisory Circular (AC) 120-27 "Aircraft Weight and Balance Control". Justification for aspects of the definition is discussed. Example values using data from 2003 through 2018 are shown. Results are applicable to Operation Specifications (OpSpecs) approval using survey-derived average weight values.

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PROBLEM STATEMENT

US aviation regulations and Operations Specifications (OpSpecs A097, A098, and A099) require an approved weight and balance control system based on average, assumed, or estimated weight. For passengers and crew, establishing an average body weight by sample weighing is disruptive to operations and is viewed unfavorably as an intrusion on privacy by the US traveling public.

Since 1968, the Federal Aviation Administration (FAA) has established standard average weights for airline passengers and crew and published them in Advisory Circular (AC) 120-27 “Aircraft Weight and Balance Control”. Since revision D of AC 120-27, published in 2004, these standard average weights have been based on data published by US Centers for Disease Control (CDC) National Health and Nutrition Examination Survey (NHANES).

Revision F of AC 120-27, published in May 2019, deletes the standard average weight values. FAA Policy Notice 8900.551, published June 11, 2020, makes it mandatory for US operators to establish new weight values consistent with AC 120-27F unless actual weights are used.

AC 120-27F still allows operators to use NHANES to establish new average weights for passengers and crew. However, summary publications by NHANES, including those referred to in FAA guidance, conflict with FAA definitions of terms such as “Child” and “Adult”. Furthermore, CDC summary statistics exclude persons, such as pregnant women, who must be considered in average passenger weights determined using AC 120-27F. Thus, these summaries cannot be used directly. NHANES raw data, which does not make these exclusions, must be used. AC 120-27F does not define a specific acceptable method to apply the NHANES raw data.

Therefore, a method to establish average weights for passengers and crew using CDC NHANES raw data, consistent with FAA requirements and definitions, is needed.

SYSTEMS CONSIDERATIONS

The ability to apply new values in existing weight and balance control systems is also a critical requirement. A general solution for novel system designs is beyond the scope of this paper, but certain aspects of existing systems are well known and should be considered.

Age and gender categories are consistently defined in all revisions of AC 120-27, and these categories are a fundamental assumption in existing weight and balance control systems. These systems often access only the number of persons in each category and may be blocked from accessing more specific personal data even if it is available to an operator’s other systems.

Weight and balance control systems differ in their ability to assign average weights to each age and gender category. For example, because past guidance did not assign a weight to infants, some systems can only account for this weight by adjusting the average value used for adults, while others can assign non-zero weight to the number of infants on board.

Changing the design of these systems can introduce significant operational and safety risk and may not be possible to accomplish in the time frame required for initial implementation of new weight values.

Therefore, the needed method must be compatible with existing weight and balance control systems and consistent with past design assumptions.

METHOD DEFINITION

A method to establish average body weights, meeting the requirements and considerations given, is defined here. No claim is made that this is the only valid method, especially if different requirements and considerations apply. Even within this method, different systems considerations may yield different resulting values.

The method is defined in three parts. The first part defines mathematical steps to determine average weights for a set of FAA-defined passenger categories. The second part defines adjustments that may be required to apply the average weights in a given operator's control systems. The third part adapts the method from Parts 1 and 2 to determine average weights for crewmembers.

How to efficiently accomplish the steps and calculations defined follows in DISCUSSION, along with justification of certain aspects of the method and comparison to other statistical techniques.

Part 1, Survey-derived Average Passenger Body Weights from NHANES Data

As allowed by AC 120-27F, values are determined from NHANES raw data. The minimum essential data is:

Table 1: Minimum Required NHANES Data Fields

Field Name	Data File	Field Description
BMXWT	BMX	Measured body mass in kilograms
BMIWT	BMX	Body mass comment: 1 = Could not obtain; 2 = Exceeds scale capacity; 3 = Respondent Clothed; 4 = Medical appliance included
RIAGENDR	DEMO	Gender: 1 = Male; 2 = Female
RIDAGEYR	DEMO	Age in years at time of examination.
WTMEC2YR	DEMO	Full sample 2-year "weighting factor" to be applied to measured data to relate it to the larger US noninstitutionalized civilian population.
SEQN*	DEMO & BMX	Respondent sequence number: Functions as a unique record key to tie together data from DEMO and BMX files.

**SEQN is required only to join records in the BMX file to associated records in the DEMO file.*

As recommended in NHANES Analytic Guidelines and Tutorial, consecutive 2-year cycles are combined into a 4-year cycle. (The most recent 4-year cycle combines 2015-2016 and 2017-2018.) In the formulas below, WTMEC is the 4-year weighting value, which for 2003 – 2018 is half of the WTMEC2YR value in the raw data.

Consistent with AC 120-27E, Appendix 2, Paragraph 1. c., sample data without an examination record, with a missing body mass (BMXWT) value, or coded as clothed when weighed (BMIWT=3) are excluded.

From RIDAGEYR, age categories are defined to comply with FAA definitions in AC 120-27F, and earlier revisions. The "Infant" category is defined as persons who have not yet reached their 2nd birthday. The "Child" category is defined as persons with an age greater than or equal to 2 years who have not yet reached their 13th birthday. The "Adult" category is defined as persons with an age greater than or equal to 13 years.

For FAA definitions, gender is only considered for "Adults", and is given by RIAGENDR.

For each age and gender category, i.e. "Infant", Child", "Adult Female" and "Adult Male", the following steps are calculated independently. In formulas (1) and (2), n_R is the number of non-excluded records in the data set for each category.

Step 1) A raw weighted mean ($\overline{w}^*$) is calculated using the formula:

$$\overline{w}^* = \frac{\sum_{i=1}^{n_R} BMXWT_i \times WTMEC_i}{\sum_{i=1}^{n_R} WTMEC_i} \tag{1}$$

Step 2) Using the raw mean, a raw weighted sample standard deviation (σ^*) is calculated using the formula:

$$\sigma^* = \sqrt{\frac{\sum_{i=1}^{n_R} WTMEC_i \times (BMXWT_i - \overline{w}^*)^2}{\frac{(n_R - 1)}{n_R} \times \sum_{i=1}^{n_R} WTMEC_i}} \tag{2}$$

Step 3) Consistent with AC 120-27E, Appendix 2, sample data with BMXWT more than twice σ^* either greater than or less than $\overline{w}^*$ are excluded to form a filtered data set. (See DISCUSSION for elaboration.) In formulas (3) and (4), n_f is the number records in the filtered data set for each category.

Step 4) From the filtered data set, a weighted mean (W) is calculated using the formula:

$$W = \frac{\sum_{i=1}^{n_f} BMXWT_i \times WTMEC_i}{\sum_{i=1}^{n_f} WTMEC_i} \tag{3}$$

Step 5) From the filtered data set, a weighted sample standard deviation (σ) is calculated using the formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n_f} WTMEC_i \times (BMXWT_i - W)^2}{\frac{(n_f - 1)}{n_f} \times \sum_{i=1}^{n_f} WTMEC_i}} \tag{4}$$

Step 6) Due to NHANES sample design, the tolerable error percentage (*e*) defined in AC 120-27F should not be used to determine confidence intervals for NHANES averages. However, if an operator is required to demonstrate these values, they may be calculated using AC 120-27F, paragraph 3.3.3:

$$e = \frac{1.96 \times \sigma \times 100}{W \times \sqrt{n_f}} \tag{5}$$

The survey-derived average passenger body weights are the W values defined for Infant, Child, Adult Female, and Adult Male, labeled W_I, W_C, W_F, and W_M respectively.

Part 2, Weight Adjustments for System-specific Implementation

For application to existing systems, further adjustments may be required. In the following definitions, $[W]$ is used to represent the adjusted value used in operational systems in place of the W value calculated as defined in Part 1.

Determining these adjustments requires definition of the following quantities:

- N_I is the total number of Infants boarded
- N_C is the total number of Children boarded
- N_A is the total number of Adults boarded
- N_F is the total number of Adults boarded, known to be Female
- N_M is the total number of Adults boarded, known to be Male

N_X is the total number of Adults boarded, not known to be Female or Male

$$N_A = N_F + N_M + N_X \tag{6}$$

Values for these quantities should be determined for the operation to which the adjusted $[W]$ will be applied. For example, they might be measured by counting on representative flights for a representative time period, or estimated from existing data. Estimates for N_F, N_M, N_C, and N_I may also be obtained from the NHANES filtered data set defined in Part 1, Step 3, by dividing the total WTMEC for each category by the total WTMEC for all categories, using the formula:

$$N = \frac{\sum_{i=1}^{n_f} WTMEC_i}{\sum_{F,M,C,I}(\sum_{i=1}^{n_f} WTMEC_i)} \tag{7}$$

Additionally:

M:F is the assumed Male to Female ratio for Adults when gender is not identified; and

$[W_X]$ is the operationally assumed weight for an Adult when gender is not identified.

Values for M:F are sometimes assigned to an operator by the FAA. For example, "50:50" is stated in the FAA template for Operation Specifications A099, but "60:40" or other ratios may be given in other contexts. (When M:F = 60:40, M = 60 and F = 40.) If M:F is not defined by the FAA, use:

$$\text{M:F} = N_M : N_F \tag{8}$$

Adjusted values $[W]$ must ensure that total weight calculated by the operational system is equal to total weight calculated assuming M:F and the W values from Part 1, which is stated in the following identity: (9)

$$N_X\,[W_X] + N_M\,[W_M] + N_F\,[W_F] + N_C\,[W_C] + N_I\,[W_I] = \left(N_M + \frac{M}{M+F}N_X\right)W_M + \left(N_F + \frac{F}{M+F}N_X\right)W_F + N_C\,W_C + N_I\,W_I$$

Any set of $[W]$ values that preserve the required identity (9) is consistent with this method definition.

For a common set of system constraints, where gender is always unknown ($N_M = N_F = 0$ implying $N_X = N_A$) and infants cannot be assigned a weight (implying $[W_I] = 0$), the required identity is satisfied without adjusting Child weights (implying $[W_C] = W_C$) if the Adult weight is adjusted according to:

$$[W_X] = \frac{M\,W_M + F\,W_F}{M+F} + \frac{N_I}{N_A}W_I \tag{10}$$

Furthermore, if M:F is required to be 50:50 with $[W_I] = 0$ and $[W_C] = W_C$ then:

$$[W_X] = \tfrac{1}{2}(W_M + W_F) + \frac{N_I}{N_A}W_I \tag{11}$$

Note that if the operational system can assign a weight to infants and $\text{M:F} = 50{:}50$, then the required identity (9) could also be satisfied with $[W_I] = W_I$ and $[W_C] = W_C$ by

$$[W_X] = \tfrac{1}{2}(W_M + W_F). \tag{12}$$

Part 3, Survey-derived Average Crewmember Body Weights from NHANES Data

Definitions in Part 1 and Part 2 are applied to NHANES raw data, except with different age and gender categories.

Since the FAA defined age categories of "Infant", "Child", and "Adult" do not apply to crewmembers, a "Pilot" category is defined as persons at least 23, and less than 65, years of age and a "Flight Attendant" category is defined as persons at least 21 years of age.

The survey-derived average crewmember body weights are the W values defined for Pilot Female, Pilot Male, Flight Attendant Female and Flight Attendant Male, labeled $W_{P,F}$, $W_{P,M}$, $W_{FA,F}$, and $W_{FA,M}$ respectively.

If the gender of crewmembers actually on each flight is not known, then $[W_P]$ for Pilots and $[W_{FA}]$ for Flight Attendants must be determined. This requires a Male to Female ratio for Pilots (M_P:F_P) and a Male to Female ratio for Flight Attendants (M_{FA}:F_{FA}). Formula (10) is restated for Pilots and Flight Attendants as

$$[W_P] = \frac{M_P\, W_{P,M} + F_P\, W_{P,F}}{M_P + F_P} \;\; and \;\; [W_{FA}] = \frac{M_{FA}\, W_{FA,M} + F_{FA}\, W_{FA,F}}{M_{FA} + F_{FA}} \tag{13}$$

For crew members other than pilots and flight attendants, the weight for the category that more closely aligns with crew members' duties should be used. For example, an operator might use "Pilot" weights for Flight Engineers and "Flight Attendant" weights for supernumeraries or non-certificated crewmembers.

DISCUSSION

The calculations required by METHOD DEFINITION can be accomplished in any available calculation tool, including a spreadsheet. However, more thorough analysis requires tools meant specifically for statistical work. A text-based tool allows inclusion of the analysis steps and results in this paper. "R", an analysis tool accessible to many data analysts and operations engineers, is therefore used here.

It is hoped the style used will be readable by those accustomed to working with data, even without extensive background in the language. Full R scripts, with instructions for getting started in R, are included in an Appendix. Code fragments in this section should be executed in the order presented. For clarity, fixed-width font is used with executable code shown in `blue`, descriptive comments in `green`, and any output generated in `orange`, starting with:

```
# The 'dplyr' library simplifies and improves readability, especially with
#  'mutate()' to add calculated columns to a data table,
#  'group_by()' to define categories within the data, and
#  'summarise()' [note spelling] to calculate summary statistics
library(dplyr)
```

Note that the symbol " `%>%` " means: to the result of the commands so far on the left, next apply the action to the right.

NHANES is a rigorous scientific study of health and nutrition among US, non-institutionalized, civilian population whose scope includes numerous body size metrics. Documentation for each NHANES data release should be reviewed whenever the data is used.

- NHANES is described for the public at [www.cdc.gov/nchs/nhanes/about_nhanes.htm].
- Academically rigorous documentation, including Sample Design, Weighting Process, and Analytical Guidelines, is available in a series of papers at [wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx].
- A technical Tutorial for data analysis which discusses background concepts and includes practical examples is at [wwwn.cdc.gov/nchs/nhanes/tutorials].

- The NHANES Variable Keyword Search at [wwwn.cdc.gov/nchs/nhanes/search] can be used to determine how fields of interest are identified in the NHANES data.

Note: NHANES generally (not exclusively) uses "weight" to mean a numeric scaling factor, as in the common meaning of "weighted average", rather than a measure of gravitational mass. To avoid confusion, this section carefully uses "mass" as the object of gravity and follows the NHANES convention for "weight" despite this paper elsewhere using US aviation vernacular, including "weight and balance" for the effect of gravity.

Using documentation above, details referred to in METHOD DEFINITION and DISCUSSION were confirmed to be consistent from 2003 through 2018. Data prior to 2003 uses inconsistent definitions and this method cannot be used without changes.

NHANES uses "MEC" to refer to CDC Mobile Examination Centers in which body measurements are taken. Body mass measurements BMXWT include undergarments and an exam gown, but not other clothing, unless an exception is coded using BMIWT.

In addition to the minimal data listed in Table 1, this analysis will use values identified in Table 2.

Table 2: Additional NHANES Data Fields

Field Name	Data File	Field Description
SDDSRVYR	DEMO	This variable represents the two-year data release cycle number.
RIDEXPRG	DEMO	Pregnancy status for females between 20 and 44 years of age at the time of MEC exam.
SDMVPSU	DEMO	Masked variance unit pseudo-primary sampling unit variable; used for variation and error analysis
SDMVSTRA	DEMO	Masked variance unit pseudo-stratum variable; used for variation and error analysis

When working with multiple cycles, SDDSRVYR identifies the cycle in each record. File names use the corresponding letter of the alphabet. For example, raw data for the 2017-2018 is identified in the data by SDDSRVYR = 10 and the letter "J", the tenth letter of the alphabet.

The required data files, DEMO and BMX, are freely available for download from the NHANES website. For example:

DEMO: wwwn.cdc.gov/nchs/nhanes/2017-2018/DEMO_J.XPT
BMX: wwwn.cdc.gov/nchs/nhanes/2017-2018/BMX_J.XPT

The following R commands download the required data files. Once published, these files do not change, so this only needs to be done once and not every time the analysis is repeated.

```
# Define a helper to keep cycle number and year conventions consistent
cycleYears <- function( cycle2or4, cycleNumbers )
{
  yr <- 2000+2*(cycleNumbers-1)
  sprintf('%s-%s',yr-(cycle2or4-1),yr)
}

# Define a helper to download needed data files to the working directory
downloadDataCycles <- function( cycleNumbers )
{
```

```
  for( cn in cycleNumbers ){
    files <- sapply(c( 'DEMO_%s.XPT','BMX_%s.XPT' ),sprintf,LETTERS[cn])
    for( f in files ){
      download.file(
        sprintf('https://wwwn.cdc.gov/nchs/nhanes/%s/%s',cycleYears(2,cn),f),
        f, mode='wb'
      )
    }
  }
}

# Change the working directory to one the current user can save files locally
setwd( 'C:/NHANES/' )

# Download XPT files for the cycles of interest
#  Do this just once (ever) and then comment out this line
downloadDataCycles(3:10)
```

The format of these files is SAS Transport [.XPT]. Many statistical software packages, including R, can read this format directly, which is preferred. Otherwise, the CDC provides a link to a free universal SAS file viewer [wwwn.cdc.gov/nchs/nhanes/sasviewer.aspx] which may be used to paste the data into more basic programs, such as a spreadsheet.

The following R commands read the required data files and load just the variables in Table 1 and Table 2 into memory. The qualification '`!is.na(WTMEC2YR)`' loads BMX and DEMO data for every person in the sample not missing an examination record.

```
# The 'foreign' library reads SAS Transport(XPT) files
library(foreign)

# Define a helper to load the needed data columns files in the working directory
importDataCycles <- function( cycleNumbers )
{
  allData <- data.frame(NULL)
  for( cn in cycleNumbers ){
    allData <- bind_rows(allData,left_join(
      subset(
        select(
          read.xport(sprintf('DEMO_%s.XPT', LETTERS[cn])),
          # only needed columns from the DEMO file here
          'SEQN','SDDSRVYR','RIDAGEYR','RIAGENDR','RIDEXPRG',
          'SDMVSTRA','SDMVPSU','WTMEC2YR'
        ),
        !is.na(WTMEC2YR)), # exclude participants without an exam record
        select(
          read.xport(sprintf('BMX_%s.XPT' , LETTERS[cn])),
          # only needed columns from the BMX file here
          'SEQN','BMXWT','BMIWT'
        ),
        by = 'SEQN'
      )
```

```
    )
  }
  return(allData)
}

# Load the data into memory once each session
RawData <- importDataCycles(3:10)
```

WTMEC2YR is a weight factor determined from the inverse probability that each person in the 2-year cycle exam data sample was selected from the population. It takes into account complex survey design, including oversampling, non-response, and post-stratification adjustments and is based on population data from the US Census Bureau. This weighting factor should be applied to relate data from MEC sample records in a 2-year cycle to the study population.

NHANES Analytic Guidelines recommend merging consecutive 2-year cycles into 4-year cycles to improve accuracy. To relate data from MEC sample records in a 4-year cycle to the study population a different weight factor, called WTMEC4YR, must be calculated. NHANES samples for years 2003-2018 were designed so that the correct values of WTMEC4YR are exactly half of the published value of WTMEC2YR. This is illustrated in [https://wwwn.cdc.gov/nchs/nhanes/tutorials/module3.aspx]. While average passenger body mass W is defined using a 4-year cycle with WTMEC = WTMEC4YR = WTMEC2YR/2, for data comparison formulas (1) thru (4) and (7) are also used here for 2-year cycles with WTMEC = WTMEC2YR.

NHANES Analytical Guidelines also describes the sample selection method as "stratified, multi-stage probability sample design" for which exact mathematical formulas for variance estimates do not exist. Instead, the National Center for Health Statistics (NCHS) recommends "Taylor series linearization methods for variance estimation in analyses of NHANES data for 2-year cycles or combined cycles". In R, this is provided by `library(survey)`. This method of variance estimation requires information regarding the survey strata and sampling units which indicate how the sample persons were selected from the study population. These survey design parameters are encoded in the SDMVSTRA and SDMVPSU fields. When analyzing any subset of the sample, this variance estimation requires design parameters for both the records included and those excluded. Thus, when excluding data from any analysis, new fields are added to indicate whether each record is part of the included subset instead of deleting the excluded records.

In R, the required indicator fields, along with age and gender categories as defined by FAA (and by CDC for comparison) are defined first.

```
# Create a copy with calculated columns added (preserve RawData)
#  Don't remove any rows, or survey design parameters are lost.
AllData <- mutate(RawData,
  # 'one' is needed to count records
  one    = 1,

  # combine 2-year cycles as recommended by Analytical Guidelines
  cycle4 = 2*ceiling(SDDSRVYR/2),
  WTMEC4YR = WTMEC2YR/2,

  # an alias to ease comparing 4- and 2-year cycles
  cycle2 = SDDSRVYR,
  # use with WTMEC2YR
```

```
  # make it easy to work in US units
  WTLB   = BMXWT / 0.45359237, # kg to lb

  # use cut(right=FALSE) to build age intervals that include the lower
  #  and exclude the upper boundary
  #
  # for FAA, Infants have not yet reached 2nd birthday.
  #          Children have not yet reached 13th birthday.
  faaAge = cut(RIDAGEYR, breaks=c(-Inf,        2,      13,     Inf),
            right=FALSE, labels=c(      'Infant', 'Child', 'Adult')),
  gender=factor(ifelse(RIDAGEYR>12,RIAGENDR,0),labels=c('None','Male','Female')),
  #
  # for comparison to CDC/NHSR, Adults are age 20 and over
  cdcAge = cut(RIDAGEYR, breaks=c(-Inf,      20,     Inf),
            right=FALSE, labels=c(      'Child', 'Adult'))
)

# Add columns used to filter the data, like 'inAnalysis' in tutorials
#  Don't remove any rows, or survey design parameters are lost.
AllData <- mutate(AllData,
  NotMissing  = ( !is.na(BMXWT) ),
  NotClothed  = ( !is.na(BMXWT) & (is.na(BMIWT)    | 3!=BMIWT) ),
  NotPregnant = ( !is.na(BMXWT) & (is.na(RIDEXPRG) | 1!=RIDEXPRG) )
  # for RIDEXPRG, 1=Yes, 2=No, 3=Unknown, Missing => No
)
```

Then, the NHANES survey design parameters are defined for 2-year and 4-year cycles. `svydesign` and `svyby` are library functions which apply NCHS recommended variance estimates using the survey design parameters. User defined function `svyWTLB` simply saves retyping commands to use these functions, especially to combine weighted statistics with unweighted sample size. `fmtWTLB` provides a consistent format to simplify comparing results.

```
library(survey)

# Define survey design parameters for overall dataset
NHANES2 <- svydesign(data=AllData,
  id=~SDMVPSU, strata=~SDMVSTRA, weights=~WTMEC2YR, nest=TRUE)
NHANES4 <- svydesign(data=AllData,
  id=~SDMVPSU, strata=~SDMVSTRA, weights=~WTMEC4YR, nest=TRUE)

# Define a function to get the weighted mean and standard error estimate
#  using survey design parameters and join to the unweighted count
svyWTLB <- function(design, byFormula)
{
  # Get mean, stderr, and unweighted sample size
  c <- svyby( ~WTLB, byFormula, design, unwtd.count )
  p <- svyby( ~WTLB, byFormula, design, svymean )
  # select(c,-se) excludes the standard error of the count
  # suppressMessages() just hides output of the implicit "by" columns
  suppressMessages( outData <- left_join(select(c,-se), p) )
  return(outData)
```

```
}

# Define a function to get consistent output formatting
fmtWTLB <- function(cycleData)
{
  c2 <- match("cycle2",names(cycleData))
  if(!is.na(c2)) cycleData <- mutate(cycleData,
                                   Years=cycleYears(2,cycle2), .after=cycle2)
  c4 <- match("cycle4",names(cycleData))
  if(!is.na(c4)) cycleData <- mutate(cycleData,
                                   Years=cycleYears(4,cycle4), .after=cycle4)
  print.data.frame( cycleData %>% mutate_if(is.numeric,round,digits=1) )
}
```

The R commands so far can be checked by comparing their results values published by the CDC in National Health Statistics Reports (NHSR). Report Number 122 gives summary data from NHANES and details how these were determined using 2-year cycles, CDC age categories, and excluding pregnant women. Table 2 is reproduced here, and the highlighted results recalculated with the following R command.

Table 2. Mean weight (pounds) among men and women aged 20 and over, by survey years, age group, and race and Hispanic origin: United States, 1999–2016

Sex, age, and race and Hispanic origin	Survey years								
	1999–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	2015–2016
	Mean (standard error)								
Men									
20 and over[1] (crude)	189.1 (1.5)	191.8 (1.1)	193.5 (1.1)	196.0 (1.7)	194.7 (1.4)	196.3 (1.4)	194.4 (1.4)	197.0 (1.2)	197.8 (1.9)
20 and over[1,2] (age adjusted)	189.4 (1.5)	191.2 (1.2)	193.3 (1.1)	195.7 (1.7)	194.6 (1.4)	196.2 (1.3)	194.3 (1.4)	197.0 (1.3)	197.9 (2.0)
Age group:									
20–39	185.8 (2.0)	188.1 (1.6)	190.4 (2.3)	192.1 (2.3)	189.9 (2.1)	193.1 (1.9)	190.7 (1.9)	194.4 (2.7)	196.9 (3.1)
40–59	194.3 (2.6)	197.7 (1.5)	198.4 (2.0)	203.0 (2.5)	199.9 (2.0)	202.0 (2.4)	200.4 (2.3)	200.7 (1.8)	200.9 (2.0)
60 and over	187.8 (1.7)	186.2 (1.5)	190.0 (1.7)	190.0 (1.4)	194.0 (1.8)	192.1 (1.5)	190.5 (2.5)	195.4 (2.7)	194.7 (1.9)
Race and Hispanic origin[2]:									
Non-Hispanic white	192.3 (1.7)	194.6 (1.3)	196.3 (1.3)	197.8 (1.6)	198.2 (1.3)	199.5 (1.4)	196.7 (1.8)	200.2 (2.0)	202.2 (2.4)
Non-Hispanic black	188.7 (1.7)	190.8 (1.9)	196.4 (3.8)	201.0 (1.9)	197.1 (2.0)	201.1 (2.4)	198.4 (2.1)	199.3 (2.6)	197.7 (2.6)
Non-Hispanic Asian	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	159.1 (1.6)	161.7 (1.4)	161.1 (1.3)
Hispanic[3]	--- ---	--- ---	--- ---	--- ---	184.1 (2.4)	187.0 (2.4)	187.2 (1.8)	189.6 (3.1)	190.5 (1.9)
Mexican-American	177.9 (1.6)	177.5 (1.7)	180.1 (2.1)	179.3 (2.0)	184.0 (2.7)	185.6 (2.8)	189.5 (2.5)	191.9 (2.3)	190.4 (2.5)
Women									
20 and over[1] (crude)	163.6 (1.7)	162.9 (1.2)	164.2 (1.6)	165.1 (1.7)	166.1 (1.3)	166.2 (0.9)	167.1 (1.3)	169.8 (1.3)	170.5 (1.7)
20 and over[1,2] (age adjusted)	163.8 (1.7)	162.8 (1.3)	164.1 (1.7)	164.8 (1.7)	166.3 (1.4)	166.1 (1.0)	167.2 (1.3)	170.1 (1.4)	170.6 (1.7)
Age group:									
20–39	161.9 (2.1)	158.9 (2.1)	160.6 (2.4)	160.5 (2.4)	166.6 (2.7)	164.3 (2.1)	165.1 (1.8)	169.4 (1.7)	167.6 (1.9)
40–59	169.4 (2.9)	168.6 (2.4)	171.0 (2.5)	172.3 (2.7)	170.2 (1.8)	167.8 (1.5)	172.3 (1.7)	175.2 (2.7)	176.4 (3.0)
60 and over	157.9 (1.3)	160.3 (1.4)	159.0 (1.3)	160.2 (1.9)	159.5 (1.1)	166.6 (1.3)	162.5 (2.3)	163.1 (1.7)	166.5 (2.6)
Race and Hispanic origin[2]:									
Non-Hispanic white	161.9 (2.2)	162.2 (1.3)	162.6 (2.0)	164.1 (1.9)	165.8 (2.2)	165.0 (1.2)	167.1 (1.9)	170.4 (1.8)	170.9 (2.1)
Non-Hispanic black	185.9 (2.3)	179.3 (1.9)	185.1 (2.3)	184.1 (2.3)	185.0 (3.0)	189.5 (1.9)	190.0 (2.2)	190.0 (1.9)	186.1 (2.4)
Non-Hispanic Asian	--- ---	--- ---	--- ---	--- ---	--- ---	--- ---	131.8 (1.7)	131.0 (1.8)	132.4 (1.1)
Hispanic[3]	--- ---	--- ---	--- ---	--- ---	160.7 (1.3)	160.1 (1.6)	162.4 (1.3)	166.3 (2.1)	169.0 (1.6)
Mexican-American	157.5 (2.2)	157.5 (2.1)	162.7 (2.7)	160.8 (2.3)	160.8 (0.9)	161.6 (1.4)	165.0 (2.4)	170.0 (2.2)	171.9 (1.5)

--- Data not available.
[1]Includes other races not shown separately.
[2]Age adjusted to the projected 2000 U.S. census population using age groups 20–39, 40–59, and 60 and over.
[3]Includes Mexican-American persons.
SOURCE: NCHS, National Health and Nutrition Examination Survey, 1999–2016.

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```
# confirm definitions above here are correct by comparing to
#  https://www.cdc.gov/nchs/data/nhsr/nhsr122-508.pdf

 fmtWTLB( svyWTLB( subset( NHANES2, NotPregnant ), ~cycle2+cdcAge+gender ) ) %>%
  filter(cdcAge=='Adult'&cycle2<10) # NHSR Table 2 has Adults only

   cycle2     Years cdcAge gender counts  WTLB  se
1       3 2003-2004  Adult   Male   2247 193.5 1.0
2       4 2005-2006  Adult   Male   2242 196.0 1.7
3       5 2007-2008  Adult   Male   2755 194.7 1.4
4       6 2009-2010  Adult   Male   2896 196.3 1.4
5       7 2011-2012  Adult   Male   2591 194.4 1.4
```

```
6        8 2013-2014  Adult   Male   2645 197.0 1.2
7        9 2015-2016  Adult   Male   2584 197.8 1.9
8        3 2003-2004  Adult Female   2201 164.2 1.6
9        4 2005-2006  Adult Female   2129 165.1 1.7
10       5 2007-2008  Adult Female   2805 166.2 1.3
11       6 2009-2010  Adult Female   3039 166.3 0.9
12       7 2011-2012  Adult Female   2602 167.1 1.3
13       8 2013-2014  Adult Female   2823 169.8 1.3
14       9 2015-2016  Adult Female   2757 170.5 1.7
```

(In this and subsequent output, the first column is an automatically generated row number for reference only.)

Data in the NHSR report was calculated using SUDAAN software rather than R, yet comparing the output above to highlighted values in the published table shows an almost exact match, with no difference greater than 0.1 lb. This substantiates that the raw data is loaded correctly, and calculated mean and standard error values are consistent with recommended practice by CDC/NHANES and NCHS. The same command, adjusted only to use 4-year cycles, FAA age categories, and not exclude pregnant females, produces the following values:

```
# run the same formula with faaAge, and not excluding pregnant females
#fmtWTLB( svyWTLB( subset( NHANES2, NotPregnant ), ~cycle2+cdcAge+gender ) )
 fmtWTLB( svyWTLB( subset( NHANES4, NotClothed  ), ~cycle4+faaAge+gender ) )

   cycle4      Years faaAge gender counts  WTLB  se
1       4 2003-2006 Infant   None   1578  21.5 0.2
2       6 2007-2010 Infant   None   1451  21.0 0.2
3       8 2011-2014 Infant   None   1212  20.9 0.2
4      10 2015-2018 Infant   None   1172  21.0 0.2
5       4 2003-2006  Child   None   4352  66.8 0.6
6       6 2007-2010  Child   None   4373  66.3 0.7
7       8 2011-2014  Child   None   4501  67.5 0.8
8      10 2015-2018  Child   None   3890  67.5 0.6
9       4 2003-2006  Adult   Male   6233 189.9 0.9
10      6 2007-2010  Adult   Male   6603 191.0 1.0
11      8 2011-2014  Adult   Male   6152 191.6 0.9
12     10 2015-2018  Adult   Male   5940 194.7 1.3
13      4 2003-2006  Adult Female   6593 161.7 1.2
14      6 2007-2010  Adult Female   6741 163.0 0.8
15      8 2011-2014  Adult Female   6407 165.5 0.9
16     10 2015-2018  Adult Female   6235 167.9 1.2
```

This method might not be obviously the same as METHOD DEFINITION, but in fact the definitions are identical for mean values. (Differences in variance estimates are discussed below.) To demonstrate this, a manual implementation of Steps (1) and (2) to calculate $\overline{w}^*$ (called ws in code) and σ^* (called ss in the code) follow.

```
# A copy of the data excluding clothed sample participants
Step0 <- AllData %>% filter(NotClothed)

# Calculate a raw weighted mean, w-bar-star (ws) using Formula (1)
Step1 <- mutate(Step0, ww=WTLB*WTMEC4YR)                             %>%
  group_by(faaAge,gender,cycle4)                                     %>%
```

```
  summarise( ws=sum(ww)/sum(WTMEC4YR) )

# Sum weighted residuals (wr) for each row to get sigma-star (ss) using Formula (2)
Step2 <- left_join(Step0,Step1,by=c('faaAge','gender','cycle4'))          %>%
  mutate( wr=WTMEC4YR*(WTLB-ws)^2 )                                       %>%
  group_by(faaAge,gender,cycle4,ws)                                       %>%
  summarise( n=sum(one), ss=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )       %>%
  mutate( 'te%'=196*ss/ws/sqrt(n) )

fmtWTLB(Step2 %>% select(cycle4,faaAge,gender,n,ws,ss,'te%'))

   cycle4     Years faaAge gender    n    ws   ss te%
1       4 2003-2006 Infant   None 1578  21.5  5.6 1.3
2       6 2007-2010 Infant   None 1451  21.0  5.5 1.4
3       8 2011-2014 Infant   None 1212  20.9  5.7 1.5
4      10 2015-2018 Infant   None 1172  21.0  5.6 1.5
5       4 2003-2006  Child   None 4352  66.8 33.4 1.5
6       6 2007-2010  Child   None 4373  66.3 33.6 1.5
7       8 2011-2014  Child   None 4501  67.5 34.8 1.5
8      10 2015-2018  Child   None 3890  67.5 33.1 1.5
9       4 2003-2006  Adult   Male 6233 189.9 44.7 0.6
10      6 2007-2010  Adult   Male 6603 191.0 45.8 0.6
11      8 2011-2014  Adult   Male 6152 191.6 45.9 0.6
12     10 2015-2018  Adult   Male 5940 194.7 49.2 0.6
13      4 2003-2006  Adult Female 6593 161.7 44.1 0.7
14      6 2007-2010  Adult Female 6741 163.0 43.9 0.6
15      8 2011-2014  Adult Female 6407 165.5 45.7 0.7
16     10 2015-2018  Adult Female 6235 167.9 46.5 0.7
```

The calculated values for the raw weighted mean are identical to those calculated immediately above. The FAA Tolerable Error (te%) calculated from σ^* is expressed as a percentage of the mean, while the Taylor-series based standard error (se) has units of mass, so these values should not be compared directly.

Consistent with the purpose of NHANES as a health and nutrition study, this data represents individuals across the entire spectrum of health and nutrition conditions, including the most unhealthy and malnourished. Individuals at the extremes of such a health spectrum are likely to be underrepresented in, if not completely absent from, the flying public. Thus, when applied to aviation, extreme values in NHANES data should have a reduced effect. Care should be taken that both low and high outliers are excluded.

A standard technique to reduce the effect of extreme values is to exclude sample values which are more than a multiple of the sample standard deviation from the sample mean; twice the standard deviation is common practice.

In certain contexts, it is important to account for possible variation between the survey-derived average value and values for groups of actual passengers. Operational systems which account for this variation have assumed a $2\sigma^*$ filtering technique because of its publication in AC 120-27, revisions D and E. Choosing a consistent definition avoids having to redesign these systems. An example is AC 120-27F, Appendix D, which relies on the sigma value derived using AC 120-27E, Appendix 2.

The estimates used for sample standard deviation, σ^* and σ, are technically exact only for a simple, independent random sample selection. However, academic reviewers advised that such a simplification can be used for NHANES. This approximation has the advantage that it can be represented exactly by a formula and implemented using any calculation tool without requiring specific software.

A disadvantage which may prove pertinent in the future, when changes in NHANES data will have to be evaluated compared to the current values, is that formulas (2), (4), and (5) do not fully reflect the design of NHANES sample selection. They are thus unreliable for determining whether changes between cycles are due to randomness in sample selection or due to changes in the population. Such an analysis should be accomplished using recommended practices by CDC/NHANES and NCHS.

The defined method of filtering extreme values from the data is implemented in the following commands.

```
# Filter by excluding values more than twice ss from the raw mean
Step3 <- left_join(Step0,Step2,by=c('faaAge','gender','cycle4'))          %>%
  filter( 2 >= abs((WTLB-ws)/ss) )

# Calculate a weighted mean, W using Formula (3)
Step4 <- mutate(Step3, wr=WTLB*WTMEC4YR)                                    %>%
  group_by(faaAge,gender,cycle4)                                            %>%
  summarise( W=sum(wr)/sum(WTMEC4YR) )

# Sum weighted residuals (wr) for each row to get sigma (S) using Formula (4)
Step5 <- left_join(Step3,Step4,by=c('faaAge','gender','cycle4'))          %>%
  mutate( wr=WTMEC4YR*(WTLB-W)^2 )                                          %>%
  group_by(faaAge,gender,cycle4,W)                                          %>%
  summarise( n=sum(one), S=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )          %>%
  mutate( 'te%'=196*S/W/sqrt(n) )

fmtWTLB(Step5 %>% select(cycle4,faaAge,gender,n,W,S,'te%'))

   cycle4     Years faaAge gender    n     W    S te%
1       4 2003-2006 Infant   None 1494  21.8  5.1 1.2
2       6 2007-2010 Infant   None 1382  21.1  4.9 1.2
3       8 2011-2014 Infant   None 1167  20.9  5.2 1.4
4      10 2015-2018 Infant   None 1118  21.1  5.0 1.4
5       4 2003-2006  Child   None 4087  62.0 26.4 1.3
6       6 2007-2010  Child   None 4156  61.5 26.7 1.3
7       8 2011-2014  Child   None 4303  62.4 26.9 1.3
8      10 2015-2018  Child   None 3692  62.9 26.3 1.3
9       4 2003-2006  Adult   Male 5940 186.1 36.1 0.5
10      6 2007-2010  Adult   Male 6291 186.5 37.3 0.5
11      8 2011-2014  Adult   Male 5879 186.8 37.1 0.5
12     10 2015-2018  Adult   Male 5689 189.6 40.5 0.6
13      4 2003-2006  Adult Female 6321 155.9 35.1 0.6
14      6 2007-2010  Adult Female 6435 157.3 35.3 0.5
15      8 2011-2014  Adult Female 6125 159.3 36.4 0.6
16     10 2015-2018  Adult Female 5937 161.6 37.2 0.6
```

These are the survey-derived averages for body mass calculated in accordance with Part 1 of METHOD DEFINITION.

In Part 2 of METHOD DEFINITION, the operator should select the combinations of adjustments, or none, which are most appropriate to their systems. For some systems these may be calculated for each flight, season, or other period, while some systems require static adjustments updated only when OpSpecs are revised.

Estimated values of N for each FAA age/gender category can be determined from NHANES raw data.

```
# Calculate population fractions using Formula (7)
NN <- left_join(
  Step3 %>% group_by(cycle4,faaAge,gender) %>% summarise( Nc=sum(WTMEC4YR) ),
  Step3 %>% group_by(cycle4,             ) %>% summarise( Nt=sum(WTMEC4YR) ),
            by=c('cycle4')
               )                                                           %>%
         group_by(cycle4,faaAge,gender) %>% summarise( N=100*Nc/Nt )

fmtWTLB( NN )

   cycle4     Years faaAge gender    N
1       4 2003-2006 Infant   None  2.9
2       4 2003-2006  Child   None 15.0
3       4 2003-2006  Adult   Male 39.7
4       4 2003-2006  Adult Female 42.4
5       6 2007-2010 Infant   None  2.9
6       6 2007-2010  Child   None 14.8
7       6 2007-2010  Adult   Male 40.1
8       6 2007-2010  Adult Female 42.2
9       8 2011-2014 Infant   None  2.4
10      8 2011-2014  Child   None 14.6
11      8 2011-2014  Adult   Male 40.4
12      8 2011-2014  Adult Female 42.6
13     10 2015-2018 Infant   None  2.4
14     10 2015-2018  Child   None 13.7
15     10 2015-2018  Adult   Male 40.8
16     10 2015-2018  Adult Female 43.1
```

From this data, calculating $[W]$ values for use in operational systems is simplest with a hand calculator. For completeness, implementation of formulas (10), (11), and (12) are also shown in R.

```
library(tidyr) # for pivot

Wx <- left_join( Step5 %>% select(cycle4,faaAge,gender,W)                 %>%
  pivot_wider(names_from=c(faaAge,gender),values_from=W,names_prefix='W_'),
               NN                                                         %>%
  pivot_wider(names_from=c(faaAge,gender),values_from=N,names_prefix='N_'),
               by=c('cycle4') )                                           %>%
  rename( N_Infant=N_Infant_None, W_Infant=W_Infant_None )                %>%
  mutate(
    W_Adult_NHANES = ( N_Adult_Male   * W_Adult_Male   +
                       N_Adult_Female * W_Adult_Female
                     ) / ( N_Adult_Male + N_Adult_Female ),
    W_Adult_5050   = 0.5*( W_Adult_Male + W_Adult_Female ),      # Formula 12
```

```
    dW_Infant_NHANES = N_Infant / ( N_Adult_Female + N_Adult_Male ) * W_Infant,

    'W_Adult_NHANES+Infant' = W_Adult_NHANES + dW_Infant_NHANES, # Formula 10
    'W_Adult_5050+Infant'   = W_Adult_5050   + dW_Infant_NHANES, # Formula 11
  )

fmtWTLB( Wx %>% select(cycle4,W_Adult_NHANES,W_Adult_5050,dW_Infant_NHANES) )

  cycle4     Years W_Adult_NHANES W_Adult_5050 dW_Infant_NHANES
1      4 2003-2006          170.5        171.0              0.8
2      6 2007-2010          171.6        171.9              0.7
3      8 2011-2014          172.7        173.0              0.6
4     10 2015-2018          175.3        175.6              0.6

fmtWTLB( Wx %>% select(cycle4,'W_Adult_NHANES+Infant','W_Adult_5050+Infant') )

  cycle4     Years W_Adult_NHANES+Infant W_Adult_5050+Infant
1      4 2003-2006                 171.3               171.7
2      6 2007-2010                 172.3               172.7
3      8 2011-2014                 173.3               173.6
4     10 2015-2018                 175.9               176.2
```

In the data shown, the weight increase resulting from a "50:50" M:F ratio compared to a ratio estimated from NHANES does not exceed half a pound, which is comparable in scale to rounding to whole pounds.

Anecdotally, fewer adults travel with infants than have infant children, so using the proportion of Infants to Adults in the NHANES population almost certainly over-estimates the body mass of Infants on typical flights. Operator-specific data is expected to reduce the magnitude of adjustments for infants, which is also comparable in scale to rounding to whole pounds.

In Part 3 of METHOD DEFINITION, appropriate ages for crewmembers differ significantly from the definition of Adult in AC 120-27F. Since age requirements for crew are not universal, the definition uses typical values. For pilots the minimum comes from 14 CFR 61.153(a)(1) for an unrestricted airline transport pilot (ATP) certificate and the maximum from 15 CFR 121.383(d) for air carrier limitations on pilot age. For Flight Attendants, the minimum age to serve alcohol in any US state has been observed as a common hiring requirement and is used here.

Commands used above to implement Steps 1 through 5 are repeated here in a condensed format, using P for Pilots and F for Flight Attendants.

```
# Repeat Part 1, Steps 1 thru 5 using ages representative of Pilots
P0 <- AllData %>% filter( NotClothed & 23<=RIDAGEYR & 65>RIDAGEYR )
P1 <- mutate(P0, ww=WTLB*WTMEC4YR)                                    %>%
  group_by(gender,cycle4)                                             %>%
  summarise( ws=sum(ww)/sum(WTMEC4YR) )
P2 <- left_join(P0,P1,by=c('gender','cycle4'))                        %>%
  mutate( wr=WTMEC4YR*(WTLB-ws)^2 )                                   %>%
  group_by(gender,cycle4,ws)                                          %>%
  summarise( n=sum(one), ss=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )   %>%
  mutate( 'te%'=196*ss/ws/sqrt(n) )
```

```
P3 <- left_join(P0,P2,by=c('gender','cycle4'))                          %>%
  filter( 2 >= abs((WTLB-ws)/ss) )
P4 <- mutate(P3, wr=WTLB*WTMEC4YR)                                       %>%
  group_by(gender,cycle4)                                                %>%
  summarise( W=sum(wr)/sum(WTMEC4YR) )
P5 <- left_join(P3,P4,by=c('gender','cycle4'))                          %>%
  mutate( wr=WTMEC4YR*(WTLB-W)^2 )                                       %>%
  group_by(gender,cycle4,W)                                              %>%
  summarise( n=sum(one), S=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )       %>%
  mutate( 'te%'=196*S/W/sqrt(n) )
fmtWTLB(P5 %>% select(cycle4,gender,n,W,S,'te%'))

  cycle4     Years gender    n     W    S te%
1      4 2003-2006   Male 2766 192.5 33.8 0.7
2      6 2007-2010   Male 3650 193.0 35.5 0.6
3      8 2011-2014   Male 3513 193.1 35.1 0.6
4     10 2015-2018   Male 3288 196.2 39.5 0.7
5      4 2003-2006 Female 3136 162.1 36.5 0.8
6      6 2007-2010 Female 3893 162.8 36.2 0.7
7      8 2011-2014 Female 3709 165.9 37.4 0.7
8     10 2015-2018 Female 3631 167.2 38.9 0.8

# Repeat Part 1, Steps 1 thru 5 using ages representative of Flight Attendants
F0 <- AllData %>% filter( NotClothed & 21<=RIDAGEYR )
F1 <- mutate(F0, ww=WTLB*WTMEC4YR)                                       %>%
  group_by(gender,cycle4)                                                %>%
  summarise( ws=sum(ww)/sum(WTMEC4YR) )
F2 <- left_join(F0,F1,by=c('gender','cycle4'))                          %>%
  mutate( wr=WTMEC4YR*(WTLB-ws)^2 )                                      %>%
  group_by(gender,cycle4,ws)                                             %>%
  summarise( n=sum(one), ss=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )      %>%
  mutate( 'te%'=196*ss/ws/sqrt(n) )
F3 <- left_join(F0,F2,by=c('gender','cycle4'))                          %>%
  filter( 2 >= abs((WTLB-ws)/ss) )
F4 <- mutate(F3, wr=WTLB*WTMEC4YR)                                       %>%
  group_by(gender,cycle4)                                                %>%
  summarise( W=sum(wr)/sum(WTMEC4YR) )
F5 <- left_join(F3,F4,by=c('gender','cycle4'))                          %>%
  mutate( wr=WTMEC4YR*(WTLB-W)^2 )                                       %>%
  group_by(gender,cycle4,W)                                              %>%
  summarise( n=sum(one), S=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )       %>%
  mutate( 'te%'=196*S/W/sqrt(n) )
fmtWTLB(F5 %>% select(cycle4,gender,n,W,S,'te%'))

  cycle4     Years gender    n     W    S te%
1      4 2003-2006   Male 4080 190.6 34.2 0.6
2      6 2007-2010   Male 5133 191.3 35.6 0.5
3      8 2011-2014   Male 4724 191.1 35.0 0.5
4     10 2015-2018   Male 4626 194.5 38.7 0.6
5      4 2003-2006 Female 4400 159.3 35.0 0.6
```

```
6       6 2007-2010 Female 5403 160.6 35.2 0.6
7       8 2011-2014 Female 4986 162.8 35.9 0.6
8      10 2015-2018 Female 4928 164.7 37.1 0.6
```

Generally, ratios for M_P:F_P and M_{FA}:F_{FA} may be estimated from an operator's total employed crewmembers. Sample calculations using 50:50 and 99:1 are shown for reference when implementing formula (13) with no claim that these ratios are applicable to any specific operation.

```
# for example only, apply sample M:F ratios for crewmembers using Formula (13)
F13 <- function(M,F,W_M,W_F) { ( M*W_M + F*W_F )/(M+F) }

fmtWTLB( P5 %>% select(cycle4,gender,W)                                  %>%
  pivot_wider(names_from=c(gender),values_from=W,names_prefix='W_P__')    %>%
  mutate( W_P_50=F13( 50,50, W_P__Male,W_P__Female ),
          W_P_99=F13( 99, 1, W_P__Male,W_P__Female )) )

  cycle4     Years W_P__Male W_P__Female W_P_50 W_P_99
1      4 2003-2006     192.5       162.1  177.3  192.2
2      6 2007-2010     193.0       162.8  177.9  192.7
3      8 2011-2014     193.1       165.9  179.5  192.8
4     10 2015-2018     196.2       167.2  181.7  195.9

fmtWTLB( F5 %>% select(cycle4,gender,W)                                  %>%
  pivot_wider(names_from=c(gender),values_from=W,names_prefix='W_FA_')    %>%
  mutate( W_FA_50=F13( 50,50, W_FA_Male,W_FA_Female ),
          W_FA_99=F13( 99, 1, W_FA_Male,W_FA_Female )) )

  cycle4     Years W_FA_Male W_FA_Female W_FA_50 W_FA_99
1      4 2003-2006     190.6       159.3   175.0   190.3
2      6 2007-2010     191.3       160.6   175.9   190.9
3      8 2011-2014     191.1       162.8   176.9   190.8
4     10 2015-2018     194.5       164.7   179.6   194.2
```

SUMMARY VALUES

The following tables show results of the METHOD DEFINITION applied to NHANES 4-year cycles from 2003 to 2018.

These values were calculated using a Microsoft Excel spreadsheet and validated using the R scripts in DISCUSSION. To the number of decimal places reported, there is no difference between calculation tools used.

Table 3: Survey-derived Average Passenger Weights from NHANES Data (LB)

NHANES 4 Yr. Cycle	Adult Male			Adult Female			Child			Infant		
	n_f	W_M	σ	n_f	W_F	σ	n_f	W_C	σ	n_f	W_I	σ
2003-2006	5940	186.1	36.1	6321	155.9	35.1	4087	62.0	26.4	1494	21.8	5.1
2007-2010	6291	186.5	37.3	6435	157.3	35.3	4156	61.5	26.7	1382	21.1	4.9
2011-2014	5879	186.8	37.1	6125	159.3	36.4	4303	62.4	29.9	1167	20.9	5.2
2015-2018	5689	189.6	40.5	5937	161.6	37.2	3692	62.9	26.3	1118	21.1	5.0

Table 4: Survey-derived Average Crewmember Weights from NHANES Data (LB)												
NHANES 4 Yr. Cycle	Pilot, Male			Pilot, Female			Flight Attendant, Male			Flight Attendant, Female		
	n_f	$W_{P,M}$	σ	n_f	$W_{P,F}$	σ	n_f	$W_{FA,M}$	σ	n_f	$W_{FA,F}$	σ
2003-2006	2766	192.5	33.8	3136	162.1	36.5	4080	190.6	34.2	4400	159.3	35.0
2007-2010	3650	193.0	35.5	3893	162.8	36.2	5133	191.3	35.6	5403	160.6	35.2
2011-2014	3513	193.1	35.1	3709	165.9	37.4	4724	191.1	35.0	4986	162.8	35.9
2015-2018	3288	196.2	39.5	3631	167.2	38.9	4626	194.5	38.7	4928	164.7	37.1

	Table 5: Adjusted Body Weights for Sample M:F Ratios (LB)							
NHANES 4 Yr. Cycle	[W_x] Not Adjusted for Infants						[W_x] Adjusted for Infants	
	Pilots		Flight Attendants		Adults	Adults	Adults	Adults
M:F	50:50	99:1	50:50	99:1	NHANES	50:50	NHANES	50:50
2003-2006	177.3	192.2	175.0	190.3	170.5	171.0	171.3	171.7
2007-2010	177.9	192.7	175.9	190.9	171.6	171.9	172.3	172.7
2011-2014	179.5	192.8	176.9	190.8	172.7	173.0	173.3	173.6
2015-2018	181.7	195.9	179.6	194.2	175.3	175.6	175.9	176.2

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APPENDIX A

To run this script, those new to R will need to install the language core, which is freely available for a variety of platforms from [www.r-project.org]. Use is simplified by installing a graphical development interface, such as RStudio Desktop (available as of writing at no cost from [rstudio.com]), and pasting the entire code into it directly. The code may be executed line by line or by selecting "Run All".

Packages required for installation are: `dplyr`, `foreign`, `survey`, and `tidyr`.

Other modifications are generally not required except to assure the path at `setwd(...)` exists and is accessible for writing. System specific details such as what directories may be accessible to the user are not addressed here.

A small font and large page are used to assist pasting from this document into plain text.

```r
#------------------------------------------------------------------------

# Script for DISCUSSION section 'NHANES USE FOR STANDARD AVERAGE BODY WEIGHT'
#  (c) 2020 Society of Aircraft Performance and Operations Engineers (SAPOE)
#
# SAPOE is a member-based organization promoting the safety and efficiency of
#  flight through knowledge of aircraft performance and weight and balance
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#  no warranty of any kind. Anyone who uses this report, or the source code
#  and data contained in it, is solely responsible for their own operations
#  and for any outcome of such use.

# The 'dplyr' library simplifies and improves readability, especially with
#  'mutate()' to add calculated columns to a data table,
#  'group_by()' to define categories within the data, and
#  'summarise()' [note spelling] to calculate summary statistics
library(dplyr)

# Define a helper to keep cycle number and year conventions consistent
cycleYears <- function( cycle2or4, cycleNumbers )
{
  yr <- 2000+2*(cycleNumbers-1)
  sprintf('%s-%s',yr-(cycle2or4-1),yr)
}

# Define a helper to download needed data files to the working directory
downloadDataCycles <- function( cycleNumbers )
{
  for( cn in cycleNumbers ){
    files <- sapply(c( 'DEMO_%s.XPT','BMX_%s.XPT' ),sprintf,LETTERS[cn])
    for( f in files ){
      download.file(
        sprintf('https://wwwn.cdc.gov/nchs/nhanes/%s/%s',cycleYears(2,cn),f),
        f, mode='wb'
      )
    }
  }
}

# Change the working directory to one the current user can save files locally
setwd( 'C:/NHANES/' )

# Download XPT files for the cycles of interest
#  Do this just once (ever) and then comment out this line
downloadDataCycles(3:10)

# The 'foreign' library reads SAS Transport(XPT) files
library(foreign)

# Define a helper to load the needed data columns files in the working directory
importDataCycles <- function( cycleNumbers )
{
  allData <- data.frame(NULL)
  for( cn in cycleNumbers ){
    allData <- bind_rows(allData,left_join(
      subset(
        select(
          read.xport(sprintf('DEMO_%s.XPT', LETTERS[cn])),
          # only needed columns from the DEMO file here
          'SEQN','SDDSRVYR','RIDAGEYR','RIAGENDR','RIDEXPRG',
          'SDMVSTRA','SDMVPSU','WTMEC2YR'
        ),
        !is.na(WTMEC2YR)), # exclude participants without an exam record
      select(
          read.xport(sprintf('BMX_%s.XPT' , LETTERS[cn])),
          # only needed columns from the BMX file here
          'SEQN','BMXWT','BMIWT'
      ),
      by = 'SEQN'
    )
    )
  }
  return(allData)
}

# Load the data into memory once each session
RawData <- importDataCycles(3:10)

# Create a copy with calculated columns added (preserve RawData)
#  Don't remove any rows, or survey design parameters are lost.
AllData <- mutate(RawData,
  # 'one' is needed to count records
  one    = 1,

  # combine 2-year cycles as recommended by Analytical Guidelines
  cycle4 = 2*ceiling(SDDSRVYR/2),
  WTMEC4YR = WTMEC2YR/2,

  # an alias to ease comparing 4- and 2-year cycles
  cycle2 = SDDSRVYR,
  # use with WTMEC2YR

  # make it easy to work in US units
  WTLB   = BMXWT / 0.45359237, # kg to lb

  # use cut(right=FALSE) to build age intervals that include the lower
  #  and exclude the upper boundary
  #
  # for FAA, Infants have not yet reached 2nd birthday.
  #          Children have not yet reached 13th birthday.
  faaAge = cut(RIDAGEYR, breaks=c(-Inf,        2,      13,     Inf),
               right=FALSE, labels=c(      'Infant', 'Child', 'Adult')),
  gender=factor(ifelse(RIDAGEYR>12,RIAGENDR,0),labels=c('None','Male','Female')),
  #
  # for comparison to CDC/NHSR, Adults are age 20 and over
  cdcAge = cut(RIDAGEYR, breaks=c(-Inf,      20,     Inf),
               right=FALSE, labels=c(      'Child', 'Adult'))
)

# Add columns used to filter the data, like 'inAnalysis' in tutorials
#  Don't remove any rows, or survey design parameters are lost.
AllData <- mutate(AllData,
  NotMissing  = ( !is.na(BMXWT) ),
  NotClothed  = ( !is.na(BMXWT) & (is.na(BMIWT)    | 3!=BMIWT) ),
  NotPregnant = ( !is.na(BMXWT) & (is.na(RIDEXPRG) | 1!=RIDEXPRG) )
  # for RIDEXPRG 1=Yes, 2=No, 3=Unknown, Missing => No
)

# Read heavily on https://wwwn.cdc.gov/nchs/nhanes/tutorials/samplecode.aspx
#  and https://wwwn.cdc.gov/nchs/data/tutorials/DB303_Fig1_R.R
library(survey)

# Define survey design parameters for overall dataset
NHANES2 <- svydesign(data=AllData,
  id=~SDMVPSU, strata=~SDMVSTRA, weights=~WTMEC2YR, nest=TRUE)
NHANES4 <- svydesign(data=AllData,
  id=~SDMVPSU, strata=~SDMVSTRA, weights=~WTMEC4YR, nest=TRUE)

# Define a function to get the weighted mean and standard error estimate
#  using survey design parameters and join to the unweighted count
svyWTLB <- function(design, byFormula)
{
  # Get mean, std error, and unweighted sample size
  c <- svyby( ~WTLB, byFormula, design, unwtd.count )
  p <- svyby( ~WTLB, byFormula, design, svymean )
  # select(c,-se) excludes the standard error of the count
  # suppressMessages() just hides output of the implicit "by" columns
  suppressMessages( outData <- left_join(select(c,-se), p) )
  return(outData)
}

# Define a function to get consistent output formatting
fmtWTLB <- function(cycleData)
{
  c2 <- match("cycle2",names(cycleData))
  if(!is.na(c2)) cycleData <- mutate(cycleData,
                               Years=cycleYears(2,cycle2), .after=cycle2)
  c4 <- match("cycle4",names(cycleData))
  if(!is.na(c4)) cycleData <- mutate(cycleData,
                               Years=cycleYears(4,cycle4), .after=cycle4)
  print.data.frame( cycleData %>% mutate_if(is.numeric,round,digits=1) )
}

# confirm definitions above here are correct by comparing to
#  https://www.cdc.gov/nchs/data/nhsr/nhsr122-508.pdf

 fmtWTLB( svyWTLB( subset( NHANES2, NotPregnant ), ~cycle2+cdcAge+gender ) ) %>%
  filter(cdcAge=='Adult'&cycle2<10) # NHSR Table 2 has Adults only

# run the same formula with faaAge, and not excluding pregnant females
#fmtWTLB( svyWTLB( subset( NHANES2, NotPregnant ), ~cycle2+cdcAge+gender ) )
 fmtWTLB( svyWTLB( subset( NHANES4, NotClothed  ), ~cycle4+faaAge+gender ) )

# A copy of the data excluding clothed sample participants
Step0 <- AllData %>% filter(NotClothed)

# Calculate a raw weighted mean, w-bar-star (ws) using Formula (1)
Step1 <- mutate(Step0, ww=WTLB*WTMEC4YR)                              %>%
  group_by(faaAge,gender,cycle4)                                      %>%
  summarise( ws=sum(ww)/sum(WTMEC4YR) )

# Sum weighted residuals (wr) for each row to get sigma-star (ss) using Formula (2)
Step2 <- left_join(Step0,Step1,by=c('faaAge','gender','cycle4'))      %>%
  mutate( wr=WTMEC4YR*(WTLB-ws)^2 )                                   %>%
  group_by(faaAge,gender,cycle4,ws)                                   %>%
  summarise( n=sum(one), ss=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )   %>%
  mutate( 'te%'=196*ss/ws/sqrt(n) )

fmtWTLB(Step2 %>% select(cycle4,faaAge,gender,n,ws,ss,'te%'))

# Filter by excluding values more than twice ss from the raw mean
Step3 <- left_join(Step0,Step2,by=c('faaAge','gender','cycle4'))      %>%
  filter( 2 >= abs((WTLB-ws)/ss) )

# Calculate a weighted mean, W using Formula (3)
Step4 <- mutate(Step3, wr=WTLB*WTMEC4YR)                              %>%
  group_by(faaAge,gender,cycle4)                                      %>%
  summarise( W=sum(wr)/sum(WTMEC4YR) )

# Sum weighted residuals (wr) for each row to get sigma (S) using Formula (4)
Step5 <- left_join(Step3,Step4,by=c('faaAge','gender','cycle4'))          %>%
  mutate( wr=WTMEC4YR*(WTLB-W)^2 )                                        %>%
  group_by(faaAge,gender,cycle4,W)                                        %>%
  summarise( n=sum(one), S=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )        %>%
  mutate( 'te%'=196*S/W/sqrt(n) )

fmtWTLB(Step5 %>% select(cycle4,faaAge,gender,n,W,S,'te%'))

# Calculate population fractions using Formula (7)
NN <- left_join(
  Step3 %>% group_by(cycle4,faaAge,gender) %>% summarise( Nc=sum(WTMEC4YR) ),
  Step3 %>% group_by(cycle4,            ) %>% summarise( Nt=sum(WTMEC4YR) ),
          by=c('cycle4')
         )                                                                %>%
       group_by(cycle4,faaAge,gender) %>% summarise( N=100*Nc/Nt )

fmtWTLB( NN )

library(tidyr) # for pivot

Wx <- left_join( Step5 %>% select(cycle4,faaAge,gender,W)                 %>%
  pivot_wider(names_from=c(faaAge,gender),values_from=W,names_prefix='W_'),
                 NN                                                       %>%
  pivot_wider(names_from=c(faaAge,gender),values_from=N,names_prefix='N_'),
                 by=c('cycle4') )                                         %>%
  rename( N_Infant=N_Infant_None, W_Infant=W_Infant_None )                %>%
  mutate(
    W_Adult_NHANES = ( N_Adult_Male   * W_Adult_Male   +
                       N_Adult_Female * W_Adult_Female
                     ) / ( N_Adult_Male + N_Adult_Female ),
    W_Adult_5050   = 0.5*( W_Adult_Male + W_Adult_Female ),      # Formula 12

    dW_Infant_NHANES = N_Infant / ( N_Adult_Female + N_Adult_Male ) * W_Infant,

    'W_Adult_NHANES+Infant' = W_Adult_NHANES + dW_Infant_NHANES, # Formula 10
    'W_Adult_5050+Infant'   = W_Adult_5050   + dW_Infant_NHANES, # Formula 11
  )

fmtWTLB( Wx %>% select(cycle4,W_Adult_NHANES,W_Adult_5050,dW_Infant_NHANES) )

fmtWTLB( Wx %>% select(cycle4,'W_Adult_NHANES+Infant','W_Adult_5050+Infant') )

# Repeat Part 1, Steps 1 thru 5 using ages representative of Pilots
P0 <- AllData %>% filter( NotClothed & 23<=RIDAGEYR & 65>RIDAGEYR )
P1 <- mutate(P0, ww=WTLB*WTMEC4YR)                                        %>%
  group_by(gender,cycle4)                                                 %>%
  summarise( ws=sum(ww)/sum(WTMEC4YR) )
P2 <- left_join(P0,P1,by=c('gender','cycle4'))                            %>%
  mutate( wr=WTMEC4YR*(WTLB-ws)^2 )                                       %>%
  group_by(gender,cycle4,ws)                                              %>%
  summarise( n=sum(one), ss=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )       %>%
  mutate( 'te%'=196*ss/ws/sqrt(n) )
P3 <- left_join(P0,P2,by=c('gender','cycle4'))                            %>%
  filter( 2 >= abs((WTLB-ws)/ss) )
P4 <- mutate(P3, wr=WTLB*WTMEC4YR)                                        %>%
  group_by(gender,cycle4)                                                 %>%
  summarise( W=sum(wr)/sum(WTMEC4YR) )
P5 <- left_join(P3,P4,by=c('gender','cycle4'))                            %>%
  mutate( wr=WTMEC4YR*(WTLB-W)^2 )                                        %>%
  group_by(gender,cycle4,W)                                               %>%
  summarise( n=sum(one), S=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )        %>%
  mutate( 'te%'=196*S/W/sqrt(n) )
fmtWTLB(P5 %>% select(cycle4,gender,n,W,S,'te%'))

# Repeat Part 1, Steps 1 thru 5 using ages representative of Flight Attendants
F0 <- AllData %>% filter( NotClothed & 21<=RIDAGEYR )
F1 <- mutate(F0, ww=WTLB*WTMEC4YR)                                        %>%
  group_by(gender,cycle4)                                                 %>%
  summarise( ws=sum(ww)/sum(WTMEC4YR) )
F2 <- left_join(F0,F1,by=c('gender','cycle4'))                            %>%
  mutate( wr=WTMEC4YR*(WTLB-ws)^2 )                                       %>%
  group_by(gender,cycle4,ws)                                              %>%
  summarise( n=sum(one), ss=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )       %>%
  mutate( 'te%'=196*ss/ws/sqrt(n) )
F3 <- left_join(F0,F2,by=c('gender','cycle4'))                            %>%
  filter( 2 >= abs((WTLB-ws)/ss) )
F4 <- mutate(F3, wr=WTLB*WTMEC4YR)                                        %>%
  group_by(gender,cycle4)                                                 %>%
  summarise( W=sum(wr)/sum(WTMEC4YR) )
F5 <- left_join(F3,F4,by=c('gender','cycle4'))                            %>%
  mutate( wr=WTMEC4YR*(WTLB-W)^2 )                                        %>%
  group_by(gender,cycle4,W)                                               %>%
  summarise( n=sum(one), S=sqrt(sum(wr)/((n-1)/n*sum(WTMEC4YR))) )        %>%
  mutate( 'te%'=196*S/W/sqrt(n) )
fmtWTLB(F5 %>% select(cycle4,gender,n,W,S,'te%'))

# for example only, apply sample M:F ratio for crewmembers using Formula (13)
F13 <- function(M,F,W_M,W_F) { ( M*W_M + F*W_F ) / (M+F) }

fmtWTLB( P5 %>% select(cycle4,gender,W)                                   %>%
  pivot_wider(names_from=c(gender),values_from=W,names_prefix='W_P__')    %>%
  mutate( W_P_50=F13( 50,50, W_P__Male,W_P__Female ),
          W_P_99=F13( 99, 1, W_P__Male,W_P__Female )) )

fmtWTLB( F5 %>% select(cycle4,gender,W)                                   %>%
  pivot_wider(names_from=c(gender),values_from=W,names_prefix='W_FA_')    %>%
  mutate( W_FA_50=F13( 50,50, W_FA_Male,W_FA_Female ),
          W_FA_99=F13( 99, 1, W_FA_Male,W_FA_Female )) )

#------------------------------------------------------------------------
```

END