Assessing Long-Term Health (LTH) Outcomes in Astronauts

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Analyses Summary and Bottom-lines

A. Assess astronaut longevity alongside cause of death and compare to the U.S. general population

- Bottom-line Up Front: Astronauts live longer when compared to the U.S. general population—e.g. only 25% of astronauts pass before their expected age of death

B. Analyze what relationship—if any—exists between the total hours flown on astronaut longevity

- Bottom-line Up Front: No relationship between premature mortality and an astronaut's spaceflight history (number of hours flown and number of flights)

C. Assessing premature mortality in those astronauts who died from cancer to gauge whether this subset dies from cancer at younger ages than those dying of cancer in the general U.S. population

- Bottom-line Up Front: Initial investigations show some evidence of astronaut deaths at younger ages compared to U.S. general population deaths due to cancer

Astronaut Data

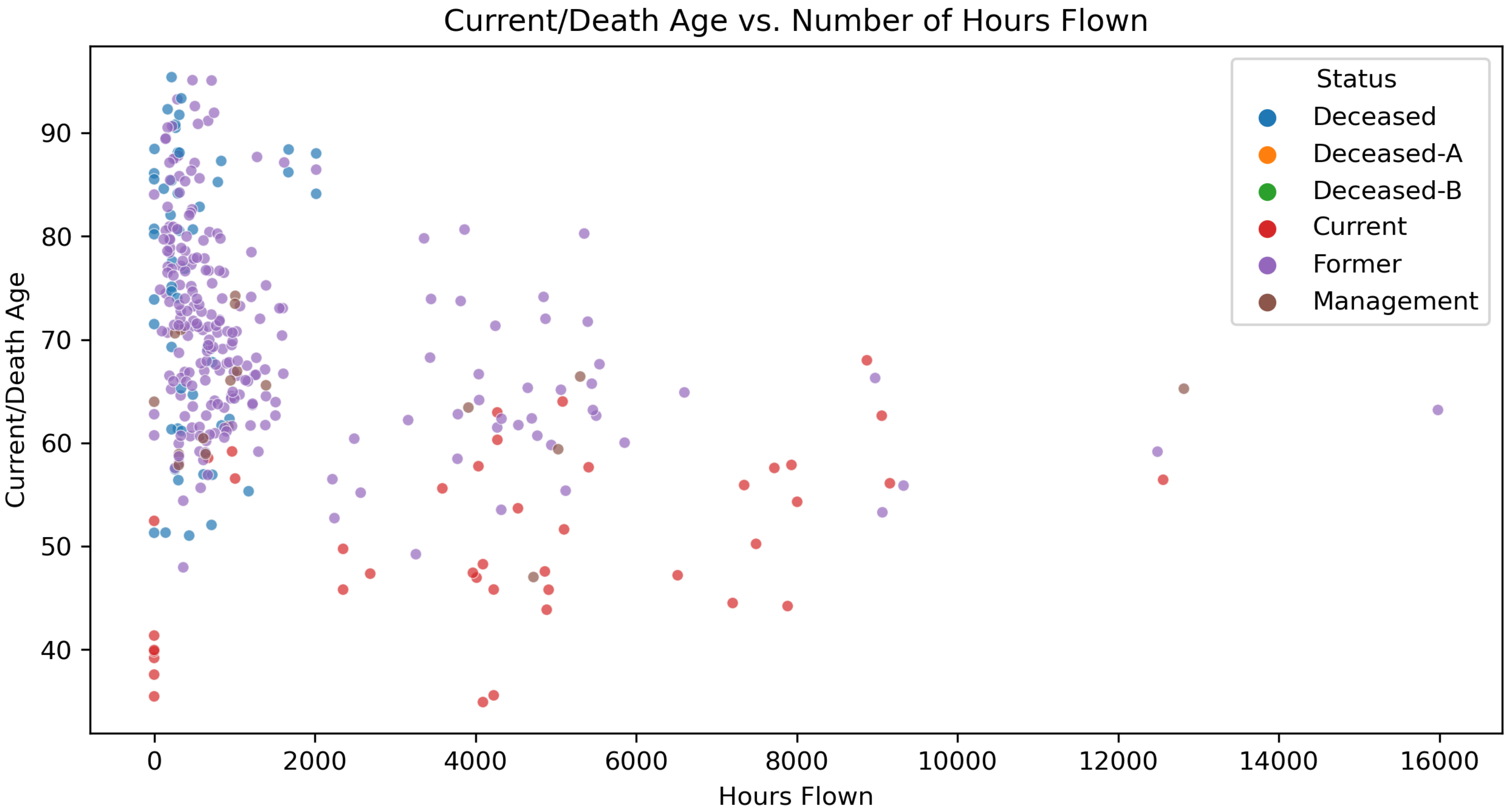
- The Long-Term Health (LTH) project focuses on post-flight and long-term concomitant risks associated with spaceflight.
- Initial development work included collection and organization of statistics about NASA astronauts, both past and present, and alive and deceased.
- The reported primary causes of astronaut deaths include cancer, other diseases, or natural causes (no further details provided in public records except “natural causes” [median age at death: 86.2]).
- Data analysis focused mainly on deceased astronauts through investigation of trends linking astronaut death details with spaceflight history
- Data was collected from publicly available resources for a total of 386 astronauts.
  - Deceased - 53 (cancer, other diseases or natural causes)
  - Deceased - 33 (disaster, accident or surgery complications)
  - Current - 42
  - Former - 248
  - Candidate - 10

Astronaut Data

- The following data were collected for each astronaut from publicly available sources:
  - Status - Candidate, Current, Former, Management, Deceased.
  - Year the astronaut was selected by NASA.
  - Group number the astronaut was selected into.
  - Total number of flights to space on any spacecraft.
  - Total cumulative hours of spaceflight time.
  - Gender, Date of Birth and Date, Cause and Details of Death.
  - Current age if living or age at death.
  - Spacecrafts Flown - Mercury, Gemini, Apollo, Skylab, Shuttle, Soyuz, Space-X and Mir, ISS.
  - Reference with details of death (obituary, newspaper article, press release).

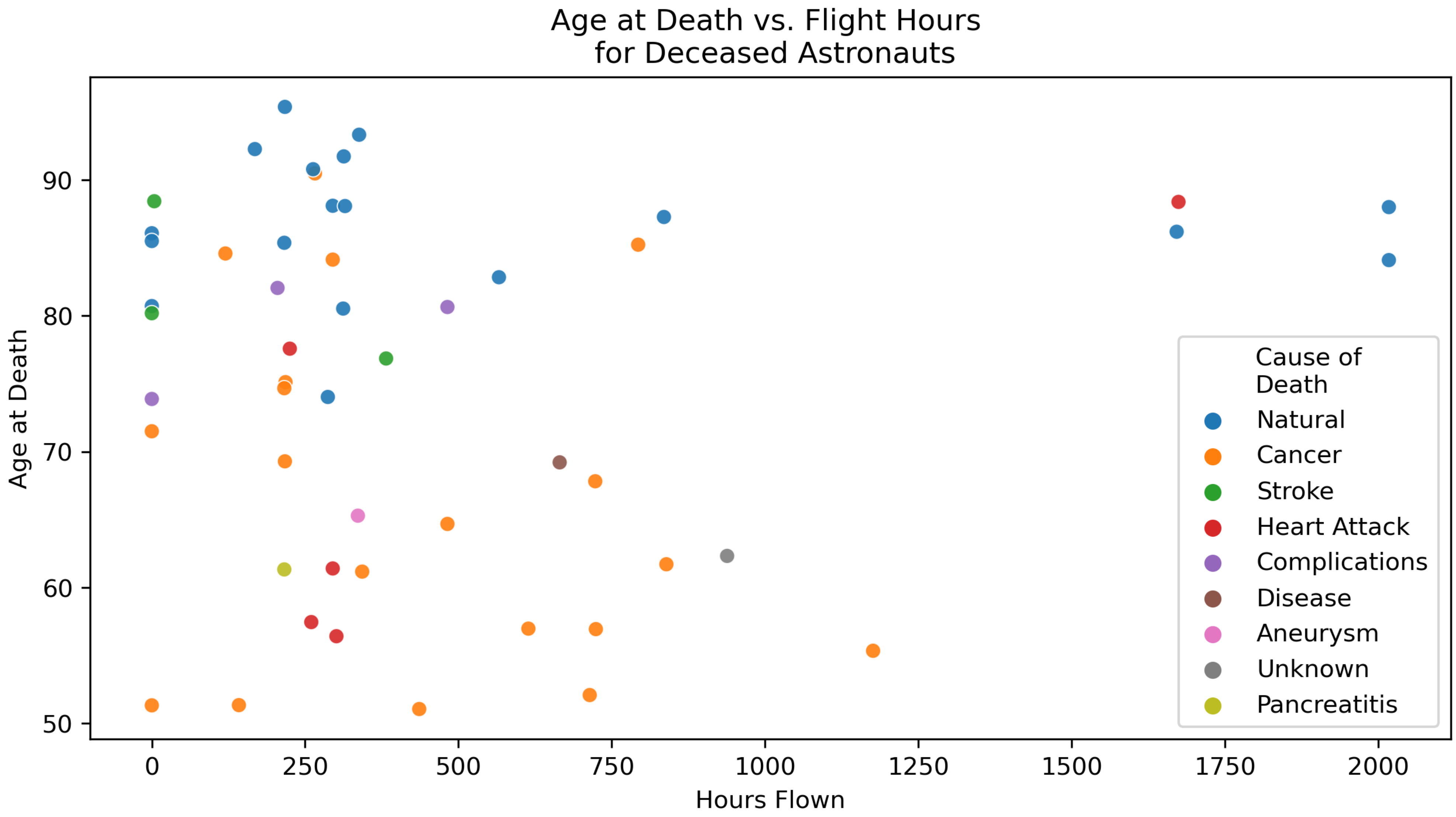
Astronaut	Status	Selection Year	Group	Flights	Total hours of space flight time	Gender	Date of birth	Date of death	Age Current or Death	Death Year - Selection Year	Cause of Death	Details of Death	Mercury	Gemini	Apollo	Skylab	Shuttle
	Deceased	1962	2	2	205	Male		08/25/2012	82.1	50	Surgery	Coronary Bypass Complications		Gemini	Apollo		
	Deceased	1963	3	2	1671	Male		05/26/2018	86.2	55	Natural	Sudden Illness			Apollo	Skylab	
	Deceased	1966	5	0	0	Male		08/11/2008	73.9	42	Natural	Long Term Asthma					
	Deceased	1996	16	0	0	Male		10/03/2009	51.3	13	Cancer	Brain Tumor					

A. Astronaut Longevity at a Glance (with Hours Flown)



The number of hours flown in space versus an astronaut's current age (or age at death if decreased). "Deceased" indicates death from natural causes. "Deceased-A" and "Deceased-B" indicate death from mission operations and death from accidental causes outside of operations (e.g. motorcycle accident), respectively.

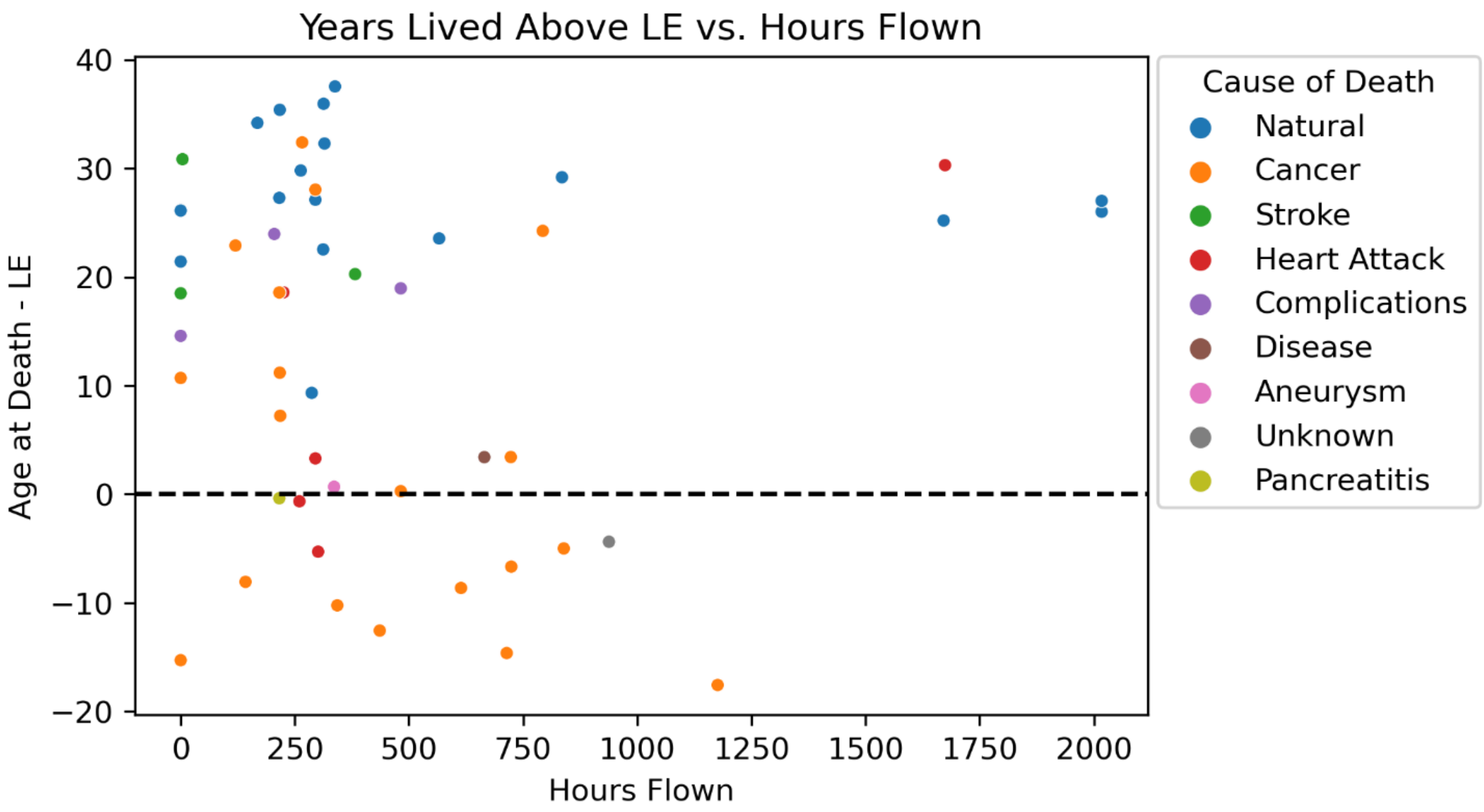
Age at Death of Deceased Astronauts vs. Hours Flown (with Cause of Death)



The number of hours flown in space versus an astronaut's age at death along with the cause of death for those who perished of natural causes.

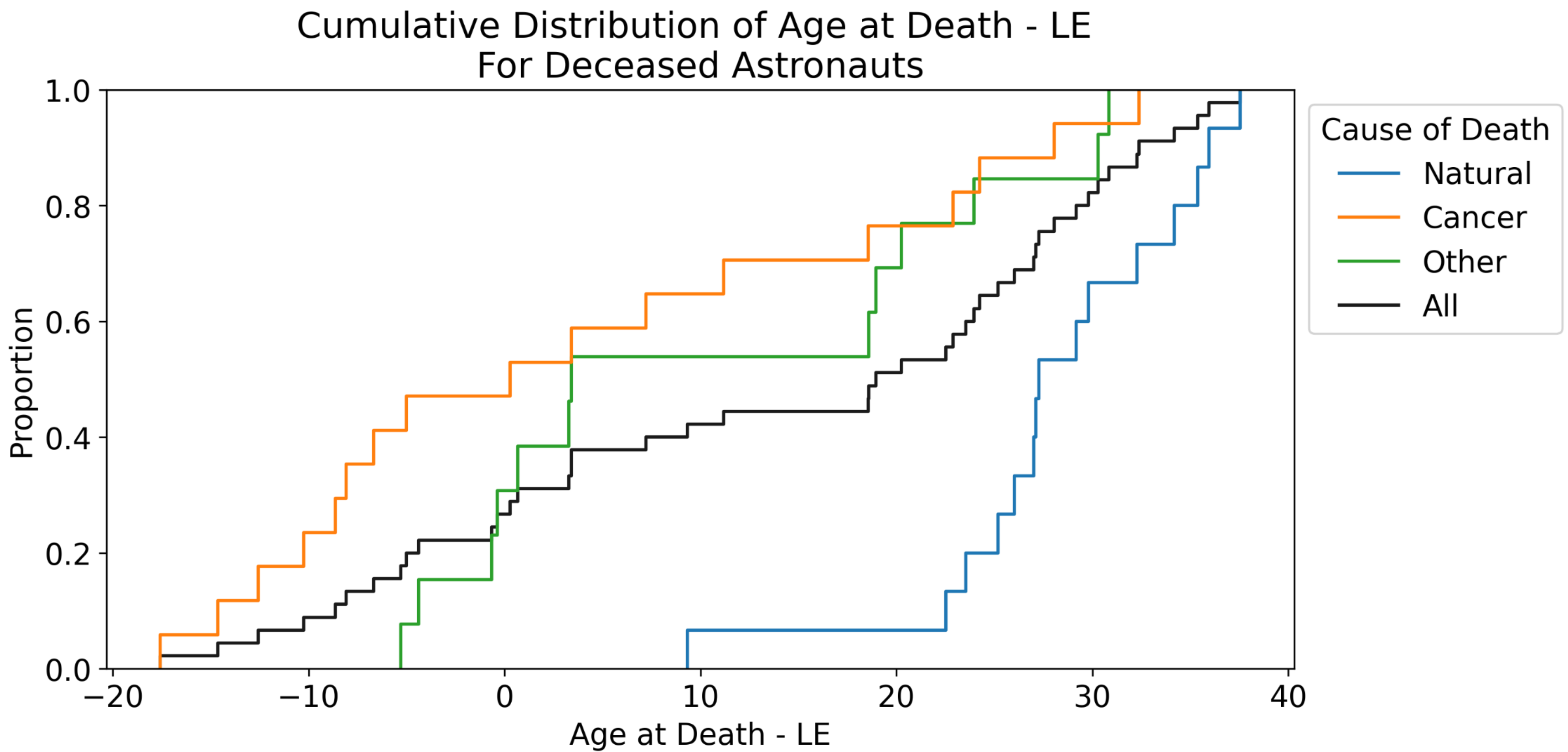
B. Years Lived Above Life Expectancy vs. Hours Flown

- Age at death minus Life Expectancy (LE) is calculated for the deceased astronaut subset to compare how long an individual lived relative to their expected age at death.
- Life expectancy figures are found using CDC mortality trends with the birth year and sex



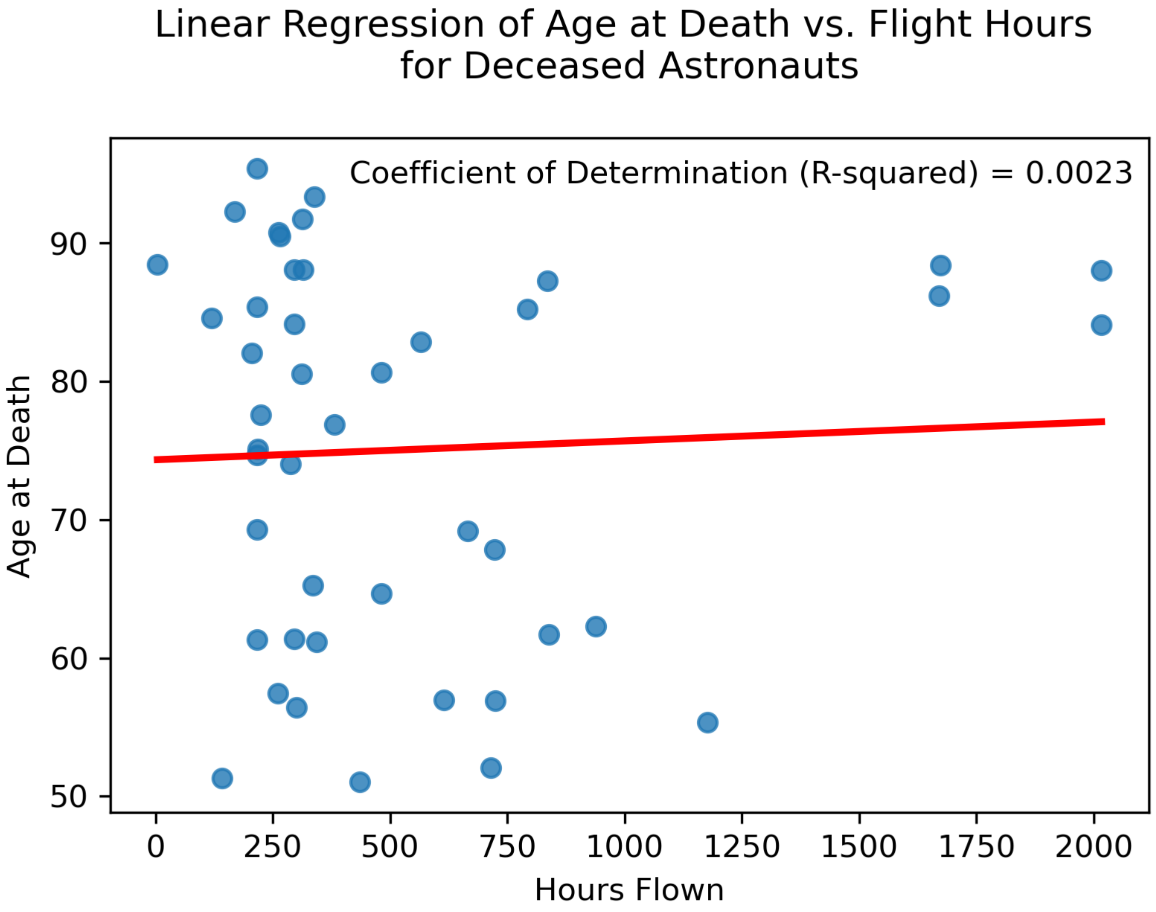
Years Lived Above Life Expectancy – Cumulative Distribution

- Only 25% of astronauts perish before their expected age of death
- Half of the decreased astronauts lived 20 or more years beyond their LE and 20% lived 30 or more years beyond
- Cancer markedly lowers the age at death distribution among astronauts



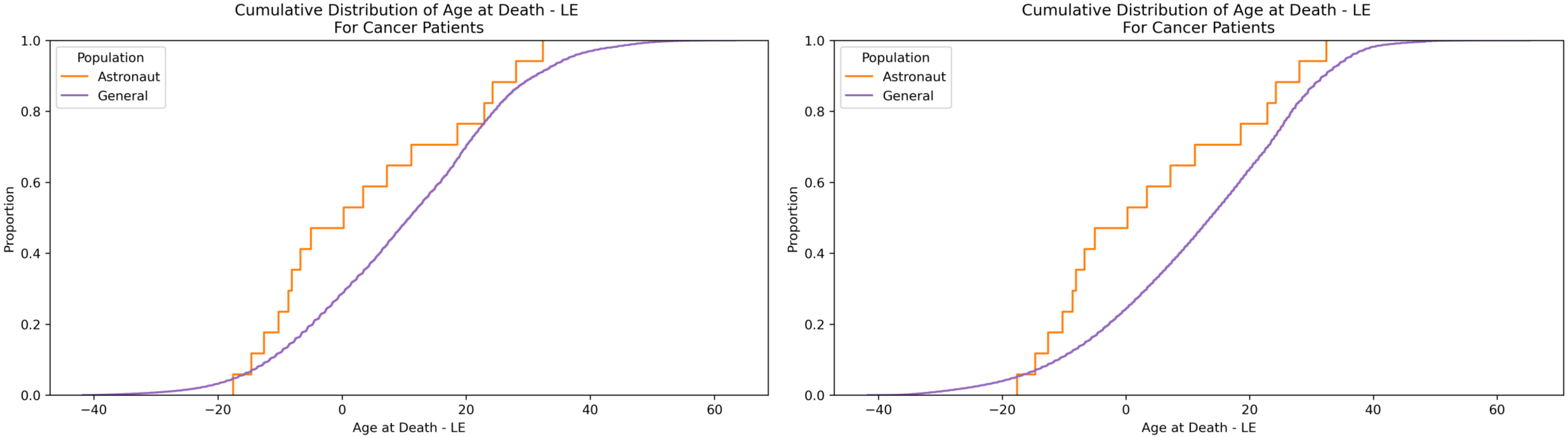
Regression with Hours Flown vs. Age at Death

- No clear relationship can be surmised between hours in spaceflight and age at death.



C. Comparing Cancer Deaths Between Astronaut and General Populations

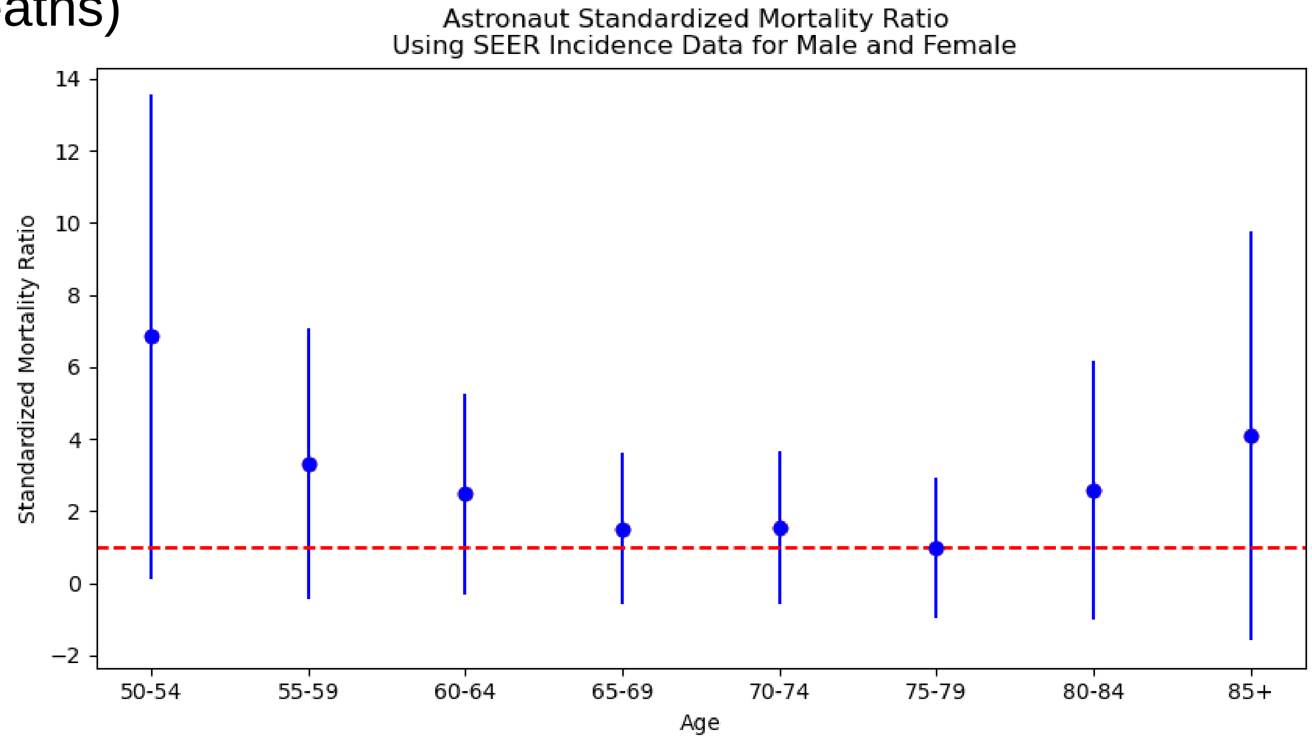
- Exploring the astronaut dataset with deaths due to cancer of any type
- The general population dying of cancer has lived more years above their life expectancy than astronauts who died of cancer
- Half of astronauts who died of cancer lived below their life expectancy versus less than 30% of general cancer patients living below their life expectancy
- Could the space environment contribute towards inducing more aggressive types of cancer?



Age at Death minus the LE for astronauts who died of cancer vs. the general population (male and female) using the CDC WONDER (left) and the Surveillance, Epidemiology, and End Results (SEER)*Stat (right) cancer datasets

Astronaut Standardized Mortality Ratios

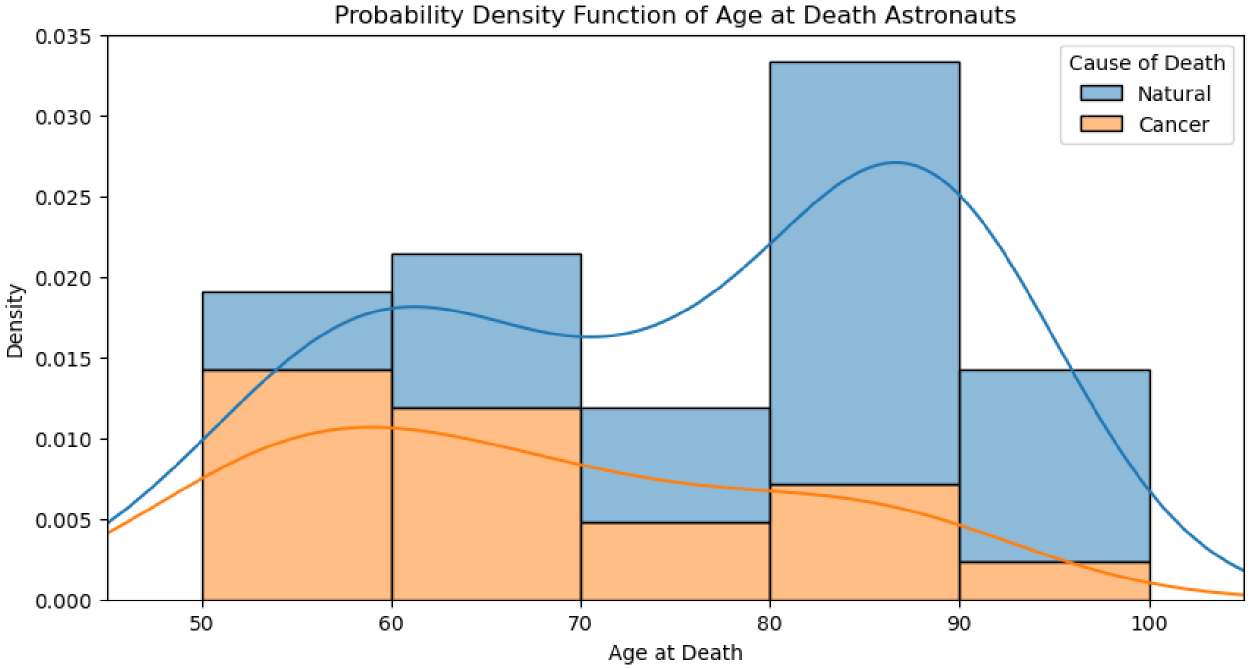
- Standardized Mortality Ratio (SMR) is the Observed Deaths / Expected Deaths
  - Quantifies how much more likely an astronaut dies of cancer versus general population
- We observe higher SMRs for astronauts in comparison to the general U.S. population using SEER incidence data
- Limitation: Very wide confidence intervals due to small dataset (e.g. 5 of the 8 age brackets have 2 or less observed deaths)

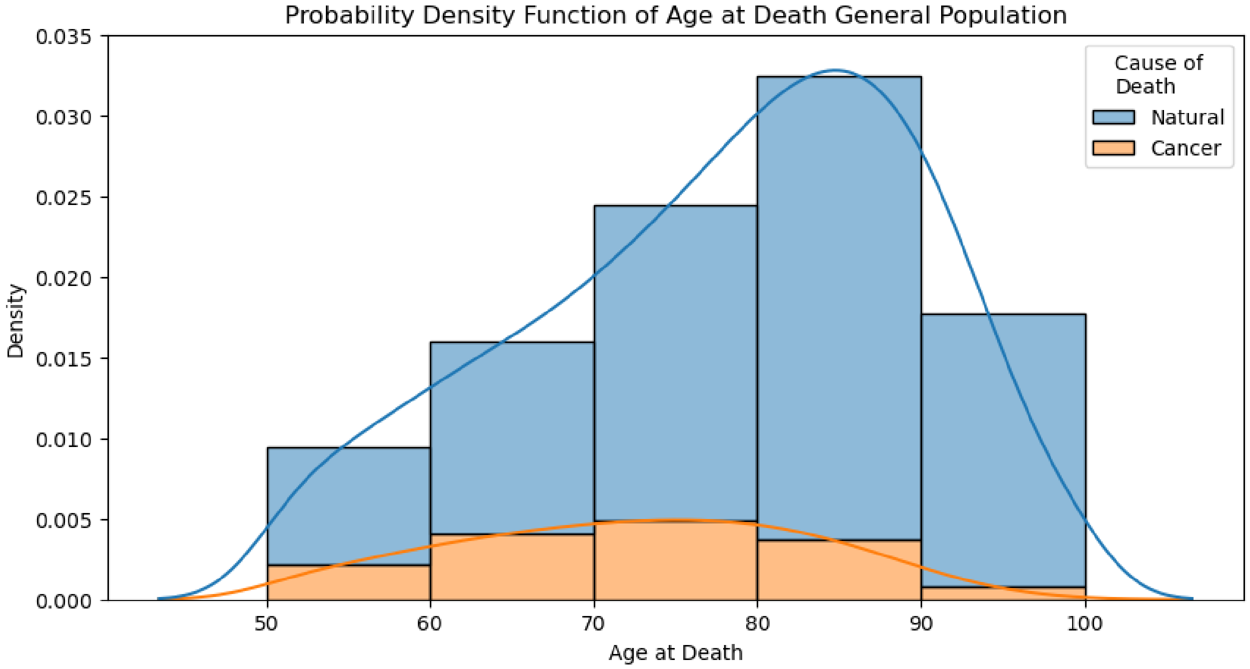


Standardized Mortality Ratios for Astronauts using the SEER Cancer Incidence-Based Mortality Rates for males and females between 1975 and 2020 with their respective 95% confidence intervals

Age at Death Probability Density Functions

- Markedly higher proportions of astronauts die of cancer than natural causes (defined as non-cancer related fatalities) in the 50-70 age bracket
- In comparison, for the general population, a relatively small proportion of the causes of death at any age bracket is due to cancer





Summary, Limitations, and Future Work

Summary:

- Astronauts generally live longer when compared to the U.S. general population—e.g. only 25% of astronauts die before their expected age of death
- The analyses of the deceased NASA astronaut data produced no evidence that the number of hours flown or number of flights are related to pre-mature mortality
- These conclusions are consistent with published literature[1, 2, 3]
- Astronaut cancer deaths happen at younger ages compared to U.S. general population cancer deaths.
  - This says nothing about the cancer survival or incidence rates where more data is needed

Limitations:

- Astronaut cause of death is often not complete/specific (type of cancer often nondisclosed from public sources)
  - **Complete access to death certificates needed to corroborate these findings**
- Data unavailable about having cancer for astronauts who died from other causes
- Any analyses performed with the astronaut datasets are limited by sample size

Future work:

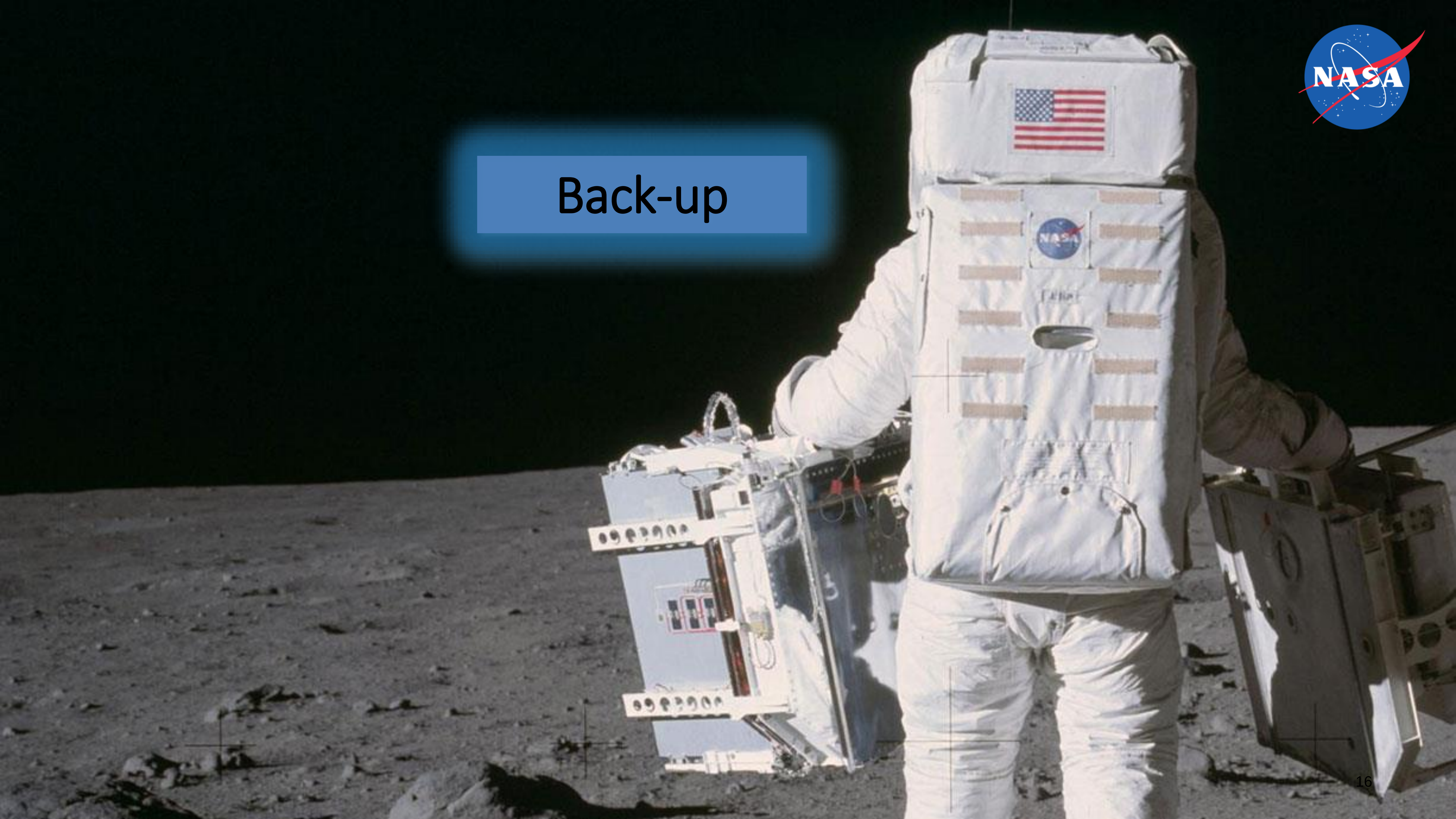
- Updating the causes of death with death certificate information, incorporating vitals into machine learning models, accessing longitudinal study data to perform robust survival analysis techniques and expand upon previous literature

Long Term Health Metric Development – Astronaut Data Papers

- [1] Reynolds RJ, Day SM. Mortality of US astronauts: comparisons with professional athletes. Occup Environ Med. 2019 Feb;76(2):114-117. doi: 10.1136/oemed-2018-105304. Epub 2018 Dec 4. PMID: 30514748.
- [2] Hamm PB, Billica RD, Johnson GS, Wear ML, Pool SL. Risk of cancer mortality among the Longitudinal Study of Astronaut Health (LSAH) participants. Aviat Space Environ Med. 1998 Feb;69(2):142-4. PMID: 9491253.
- [3] Reynolds, R. J. and Day, S. M., The Mortality of Space Explorers, Into Space - A Journey of How Humans Adapt and Live in Microgravity, doi: 10.5772/intechopen.73603, 2018.

Thank you.

Back-up



B. Life Expectancy – Premature Death Summary Table

- The median life expectancy calculated to be 61 for the subset of the astronaut population that are already deceased (using birth year and sex of the astronaut along with CDC data)
- Using a chi-squared test, the result is not significant at $p < .05$
- Not enough evidence to conclude that high flight hours (>1000) and premature death are related
- The same analysis is performed with a loftier 75 or older threshold to define premature mortality and the same conclusions are made, and, still, only 1 astronaut (Voss) flying more than 1000 hours died before age 75.
- Only 2 of the 82 astronauts who flew more than 2000 hours are deceased (aged 88 and 84.1), and only one astronaut who flew more than 1000 hours had a premature death.

	Premature Death (<61)	**Alive or Died Beyond Age 61**	**Total**
Flight Hours < 1000	11	180	191
Flight Hours > 1000	1	63	64
Total	12	243	

	Premature Death (<75)	**Alive or Died Beyond Age 75**	**Total**
Flight Hours < 1000	22	87	109
Flight Hours > 1000	1	12	13
Total	23	99	

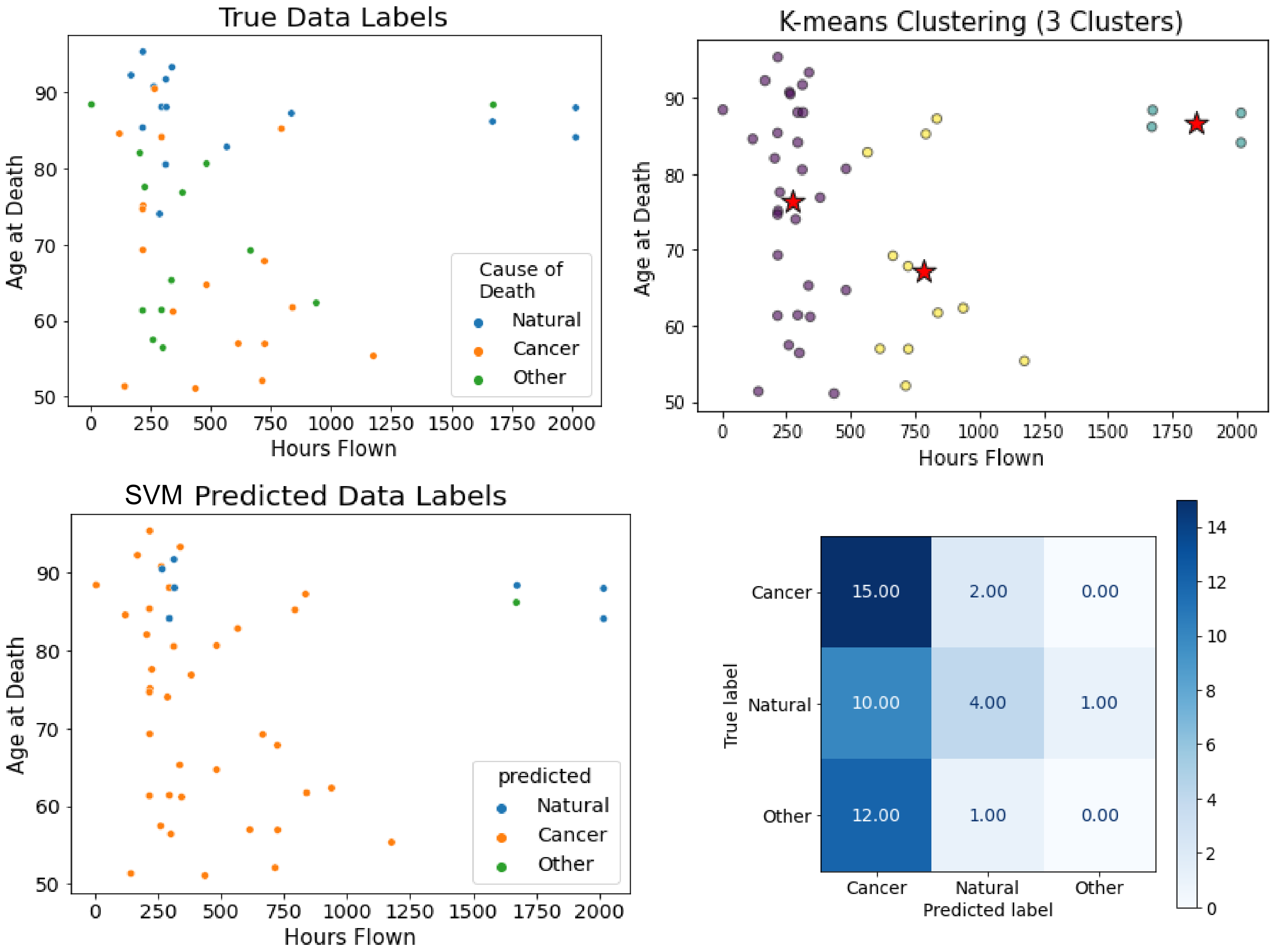
Summary table with counts of those dying before or after 61 along with flight hours being greater or less than 1000 (left). Former astronauts who are alive and already past 61 are included in the Alive or Died Beyond Age 61 column. Note that only 24 astronauts (former, deceased, or current) are currently below the median life expectancy of the deceased astronaut population while 206 are already past this age. The same analysis is performed using a higher age to define premature death (right)

Example Machine Learning Analyses with Hours Flown and Age at Death

- K-means and Support Vector Machine (SVM) machine learning analyses are performed to inform on the ability to discriminate causes of death using the number of space flight hours flown and age at death as features

- Various hyperparameter, with/without normalization, and class prediction arrangement routines are performed

- Based on the data available, results show an inability for the models to consistently predict cause of death, suggesting no clearly defined separation in the feature space



The true data labels for the classification problem (where cause of death is the class to be predicted), examples of the model using K-means and SVM, and the confusion matrix showing the results with the SVM model.

B. Life Expectancy – Summary Table and Chi-Squared Test

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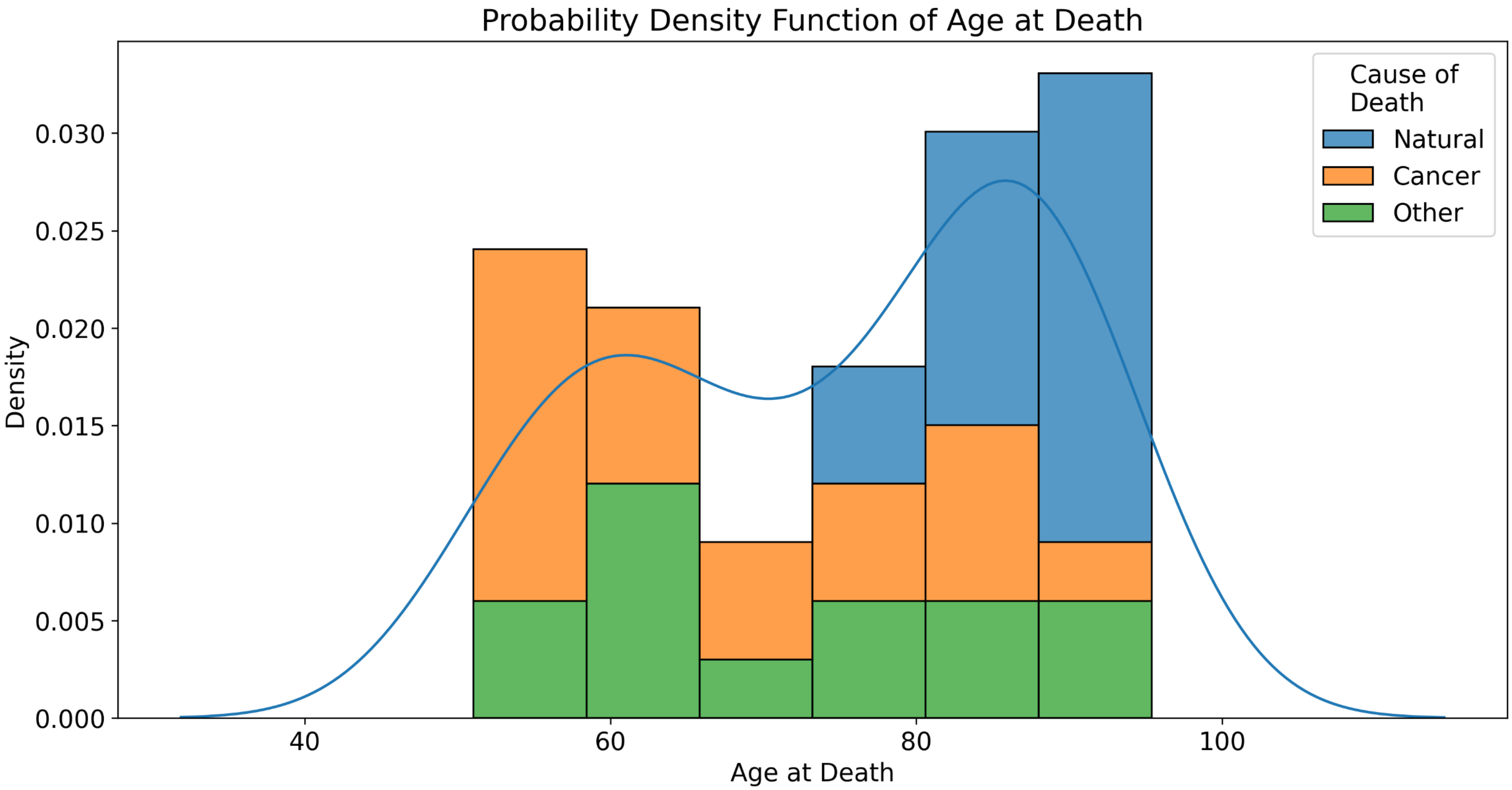
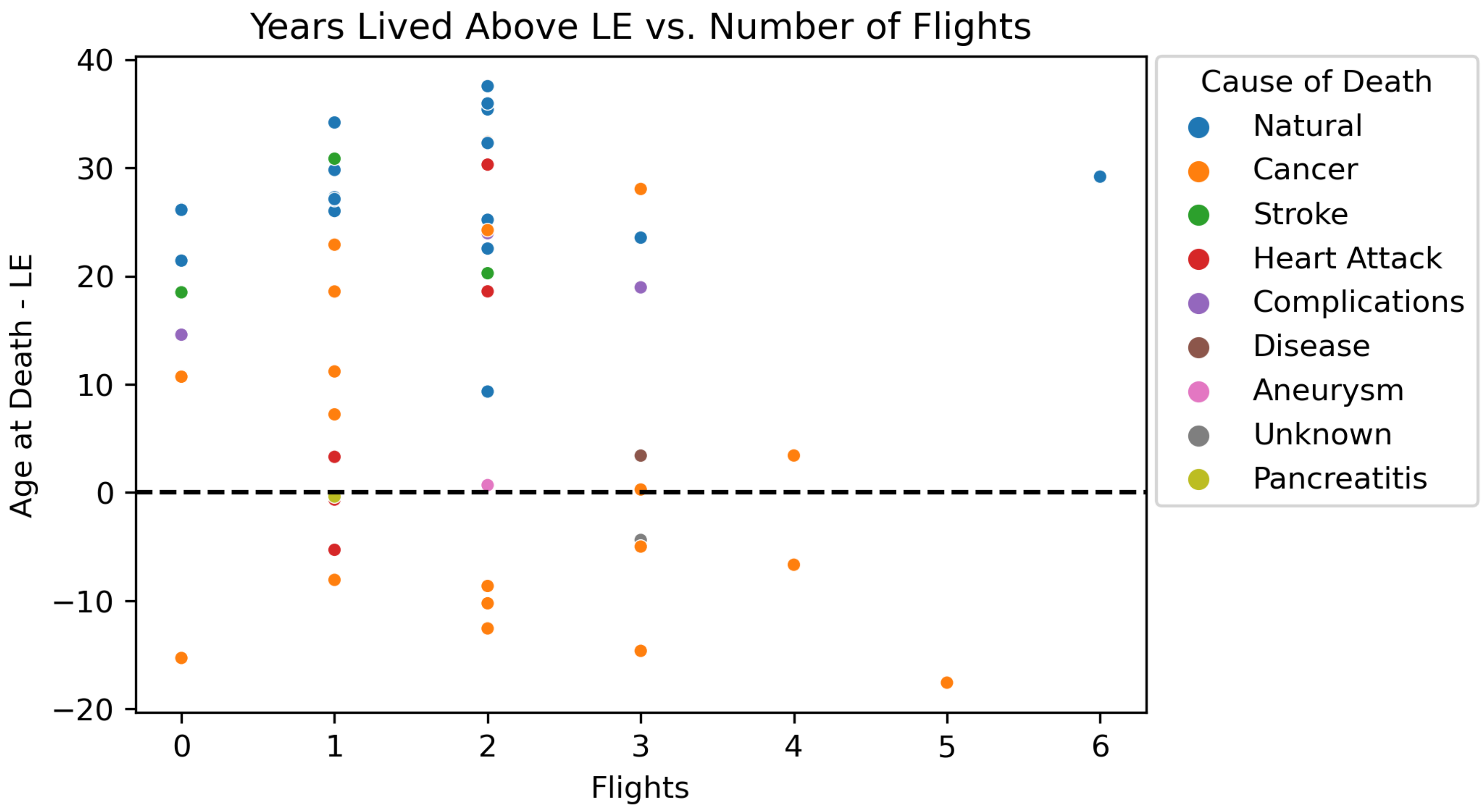
Astronaut Data Sources

- All data is from public record.
- The following sources were used to gather information on all NASA astronauts.
- Additional online sources (NASA and media) are referenced in the astronaut data spreadsheet with date and cause of death.
  - NASA Astronauts Homepage
    https://www.nasa.gov/astronauts
  - SPACEFACTS - Discover the world of astronauts
    http://www.spacefacts.de/
  - List of astronauts by year of selection
    https://en.wikipedia.org/wiki/List_of_astronauts_by_year_of_selection
  - Dead U.S. Astronauts
    https://www.wa-wd.com/l_astro.asp
  - Every US astronaut ever listed by NASA
    https://www.theguardian.com/news/datablog/2011/jul/08/us-astronauts-listed-nasa

Age at Death of Deceased Astronauts



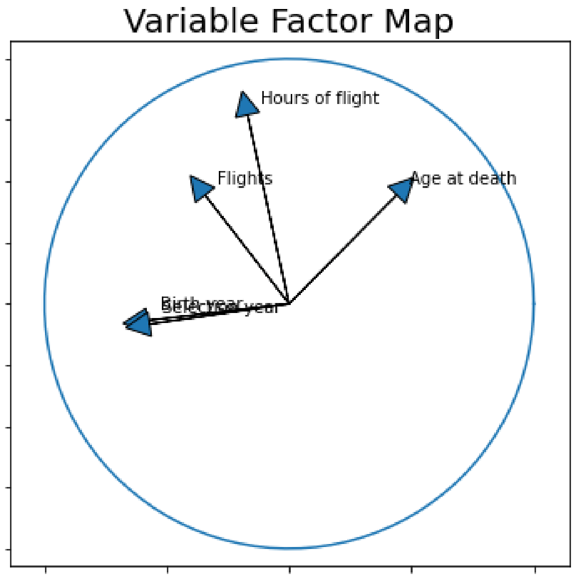
Years Lived Above Life Expectancy vs. Number of Flights



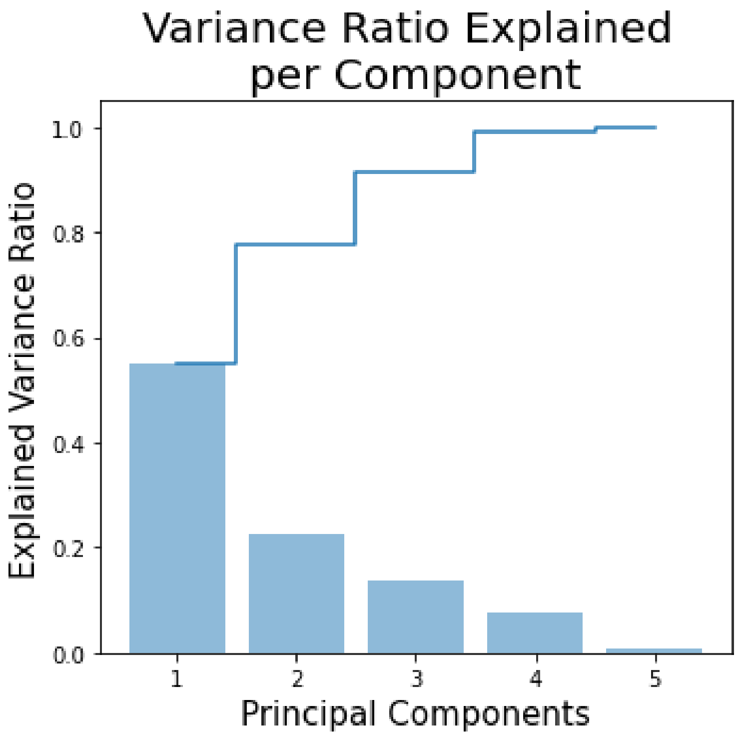
The number of flights flown versus the years lived above or below the LE of the astronaut

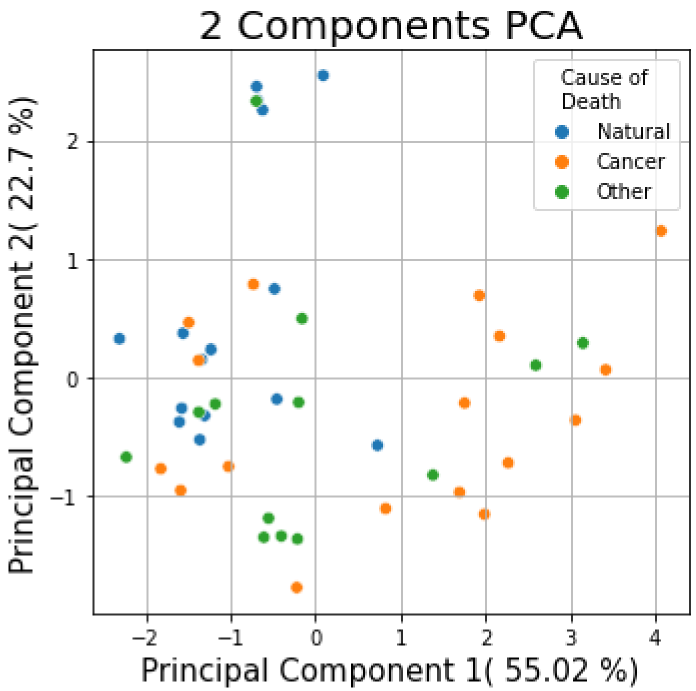
Principal Component Analysis Clustering with Multiple Variables

- A Principal Component Analysis (PCA) is performed to visualize datapoints in the space of the components with the highest variance.
- “Hours of flight”, “Flights”, “Age at death”, “Birth year”, and “Selection year” used as data variables.
- Each principal component is a linear combination of the variables.



“Birth year” and “Selection year” overlap showing their strong correlation





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