Using Historical Cost and Schedule Data to Predict Cost Risk for Future NASA X-planes

International Cost Estimation and Analysis Assication

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Introduction

- In today's cost-constrained environment, NASA should consider using historical data to establish a baseline for aeronautical cost and schedule research.

- Aircraft have various design parameters including weight, size, and speed regimes. These parameters generate a significant complexity factor that makes it difficult to estimate cost.

- Both cost and schedule assessments are needed to predict the future costs of a successful X-plane program.

Definition of an X-plane

- X-planes are a series of experimental U.S. aircraft used to test and evaluate new technologies and aerodynamic concepts.

- X-planes are not prototypes, they are complex flight research vehicles / engineering tools that are not intended to go into full-scale production.

- X-planes are usually produced in groups of 2 or 3 vehicles to ensure the completion of program objectives.

Definition of an X-plane

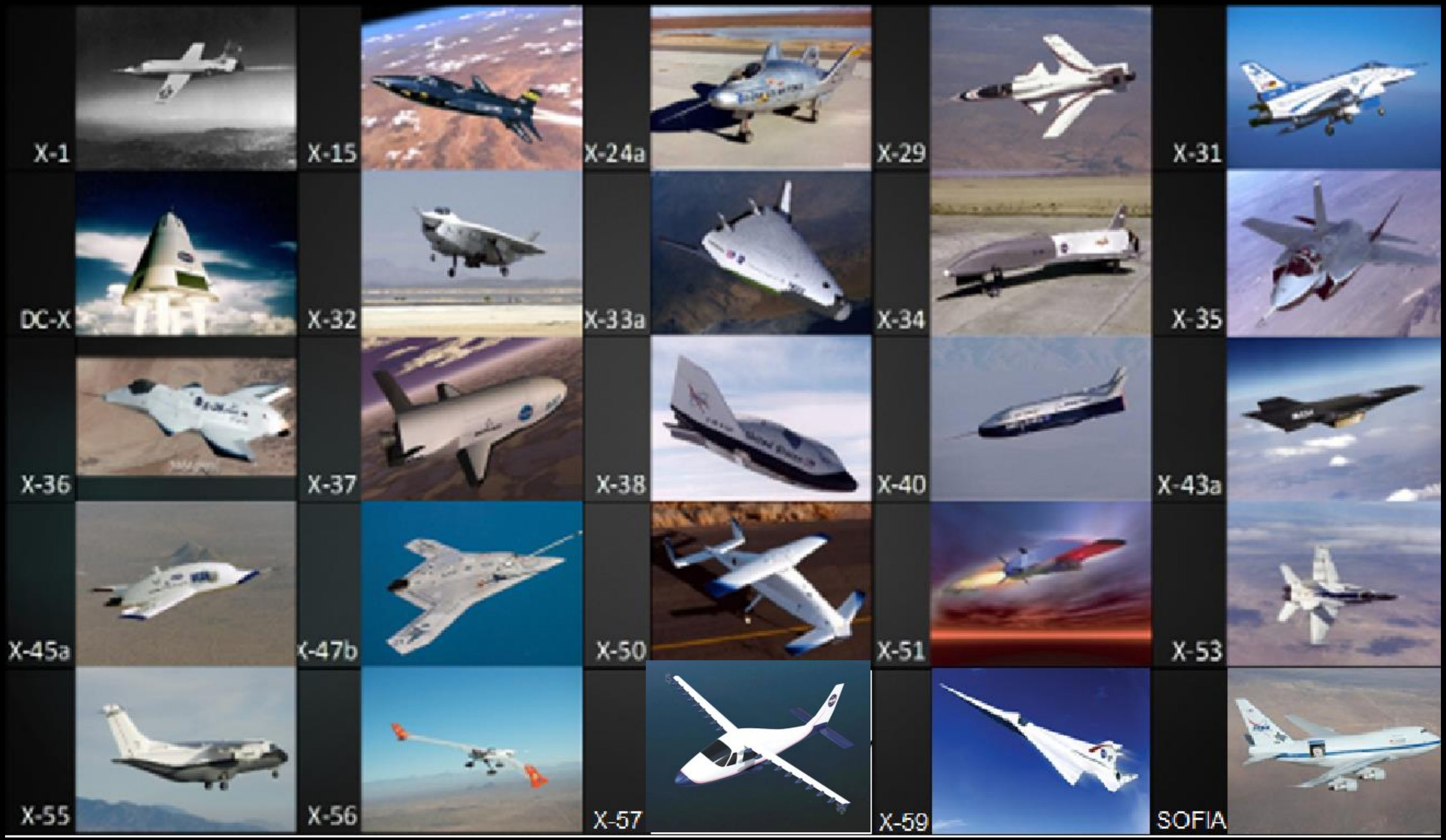
- The "X” or “experimental” designation is assigned to a U.S. research vehicle to indicate the higher risk associated with the dedicated research mission objectives.

- Not all U.S. experimental aircraft have been designated X-planes; some have been known only by the manufacturer’s designation, non-'X'-series designations, or classified code names.

Our Research Starts with X-1E Bell

The X-1 broke the sound barrier on October 14, 1947.
The X-1E is the most photographed aircraft at NASA Armstrong, yet no one seemed to know how much it cost to design, build, nor how long it took to fly all of the test cards.

Armstrong's X-Plane Database



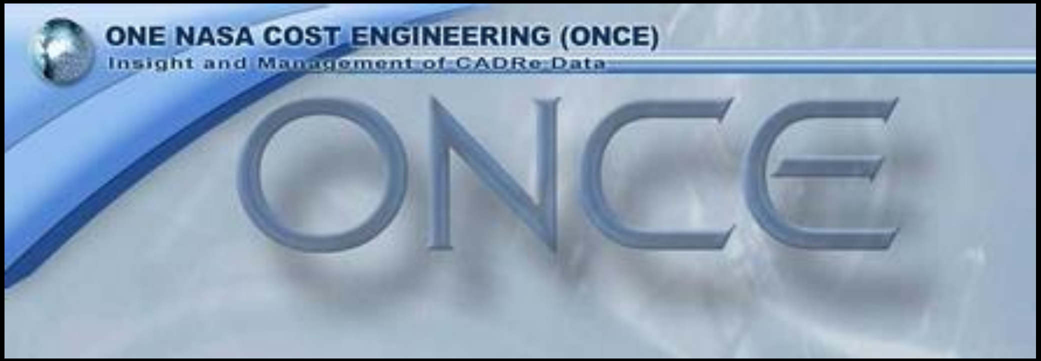
Data Timeline

- During the 1940s, -50s, -60s and -70s, projects were basically jointly funded through NACA, NASA, and various DoD programs.
- NASA Dryden (now Armstrong) was under various NASA Centers until January 1994.
- Full-cost accounting went into effect in 2002.
- Some Project Managers still have physical cost data stored:
  - Organized in three-ring binders
  - Organized by burning technical, scope, schedule, and cost data onto CDs

Data Requirements

- NASA has a Cost Analysis Data (CAD) Requirement (CADRe) for Space and Launch Vehicle like projects subject to NPR 7120.5E.

- Generally, CAD and NASA Aeronautic Centers cover CADRe for NPR 7120.8 Research and Technology Programs and Projects (X-planes).



Research Introduction

- AFRC in Edwards, California, is NASA's primary center for atmospheric flight research and operations.

- NASA is moving forward with the construction of new research planes.

- These planes will help NASA make major breakthroughs in flight technology.

Research Introduction

- This project looks to provide historical cost and schedule setback data that may be of use to future X-plane project managers.

- This project also will use historical X-plane data to calculate a risk-infused, expected cost for a notional flight research project (NFRP).

Scheduling Considerations

- One major goal for this project was to develop a database using historical X-plane cost and schedule data.
- This database outlined many types of schedule delays in completed X-plane programs.
- Schedule events were recorded if they caused a setback in a program’s intended timeline.

Why is this important?

- Each setback occurrence costs NASA valuable time and money.
- Some schedule slips cause direct costs, like the material costs resulting from repairs.
- Other slips cause indirect costs, like additional labor costs due to delays in equipment delivery.

Scheduling Considerations

- *The X-Planes: X-1 to X-45* by Jay Miller read cover-to-cover

- Documented the following details for each X-plane program:
  - Schedule slip details
  - Schedule slip duration
  - Schedule slip class
  - Schedule slip project phase

- Compiled setback information for X-1 through X-47

Setback Database

Sample of Setback Database developed for X-plane program schedule slips:

X-Plane Program	Setback Length (Months)	Setback Type	Setback Details	Setback Class	Project Phase
X-1 (second model)	1.5	Repairs	engine thrust chamber, rudder	R	D
	5	Installation	recording instrumentation	I	B
	3	Repairs	nose gear collapse, significant damage	R	D
	6	Repairs, Installation	fuel tank rust fix, new test instrumentation	R, I	C
	1	Staging	Couldn't use area until powerplant was built	De	B
X-1 (third model)	36	Development, Funding	develop turbopump longer than planned, problems with funding, lack of AF interest	D, F	A
X-1D	0.75	Repairs	nose gear fail, ungraceful landing	R	D
X-1A	5	Modifications	modifications, replacement of pressurization system	M	C
				R	
X-1B	8	Installation	NACA test instrumentation	I	B
	2	Installation	twin ventral fins	I	C
X-2	2	Repairs	nose gear collapse, damage	R	D
	36	Development, Delivery	rocket engine development and delivery longer than expected	D, De	A
	6	Development	landing instability	D	D

Schedule Findings

The 39 programs with complete data encountered a total of 74 schedule setbacks, accumulating to just over **40 years** of program delays.

Lessons Learned

- Several of the setbacks in X-plane programs tended to be repeated, avoidable issues.

- There are two major lessons that come from these issues:
  - Avoid overoptimism or arrogance when developing budget and schedule plans.
  - Clearly document all key decisions, costs, and changes to the program.

Setback Classifications

Setback findings were generalized into 8 classes of setback causes:

1.) Repairs
2.) Installations
3.) Developments
4.) Modifications
5.) Delivery
6.) Funding
7.) Political
8.) Weather.

Setback Classifications

All setback occurrences in each class were then summed and averaged to find mean setback duration in months.

Repairs	Average Length
19	4.43

Funding	Average Length
6	9.50

Installations	Average Length
8	4.44

Delivery	Average Length
8	5.13

Development	Average Length
14	11.96

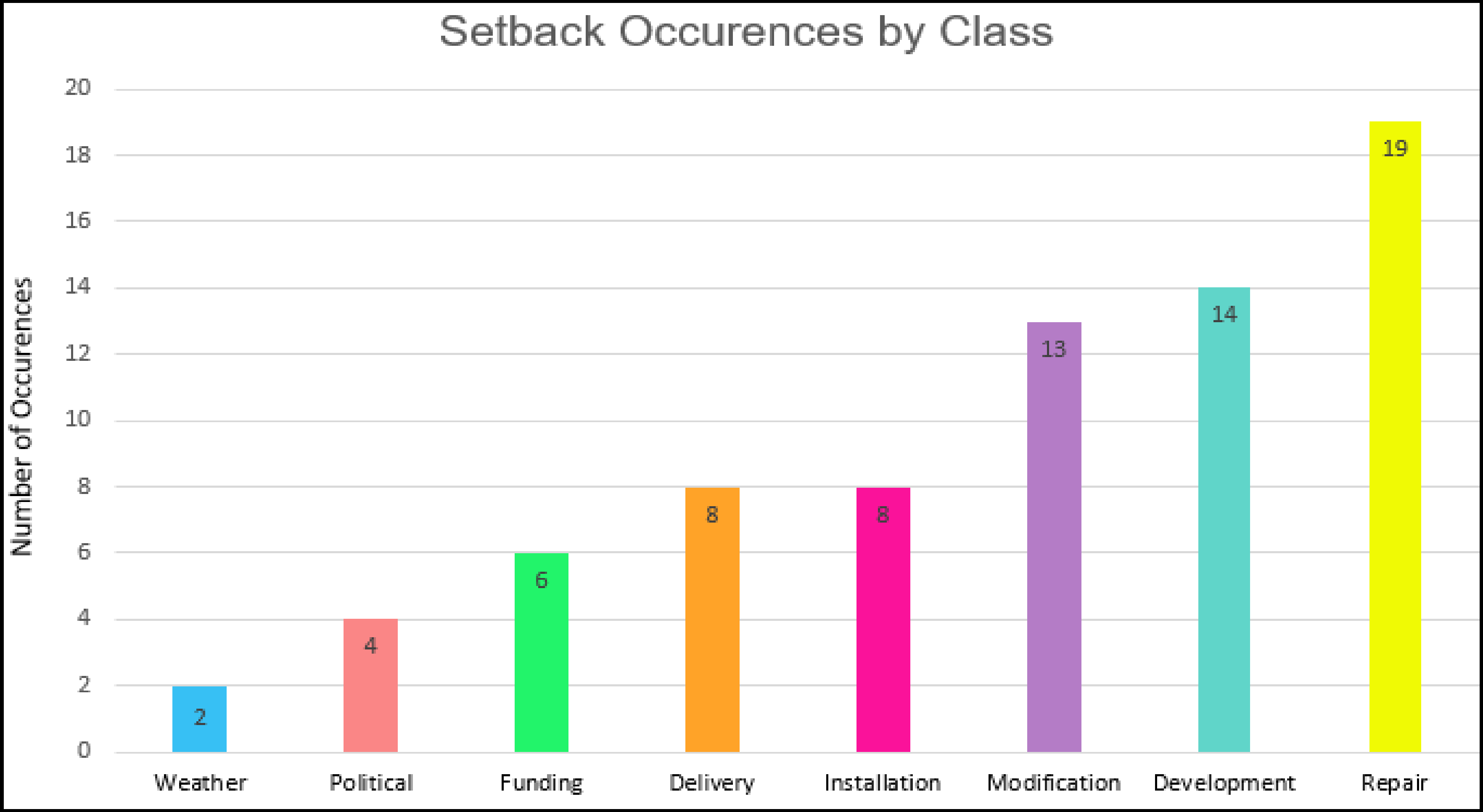
Political	Average Length
4	5.50

Modifications	Average Length
13	5.96

Weather	Average Length
2	1.25

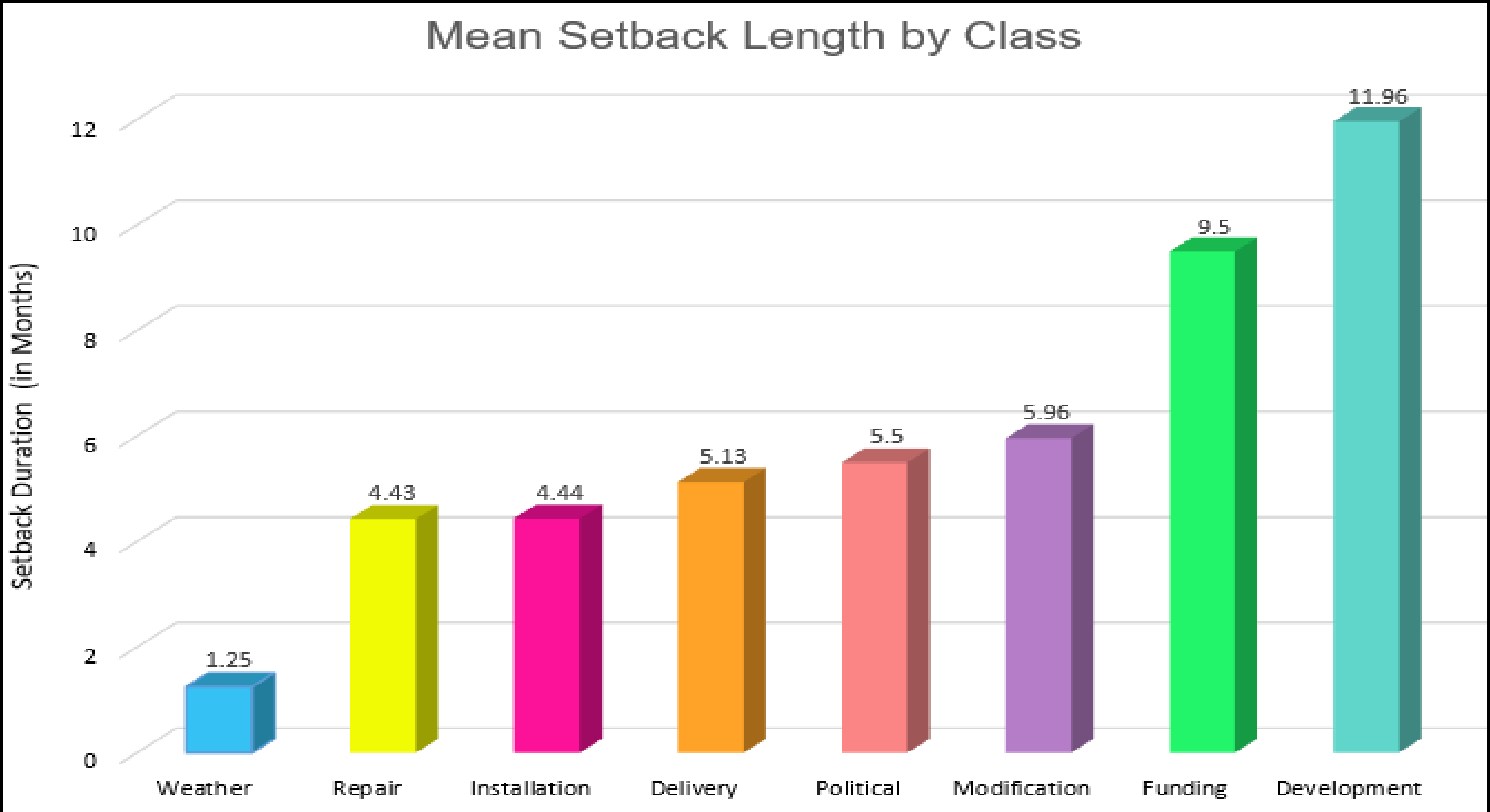
Setback Analysis

The number of recorded setback occurrences for each setback class:



Setback Analysis

The average duration of each setback class (in units of months):



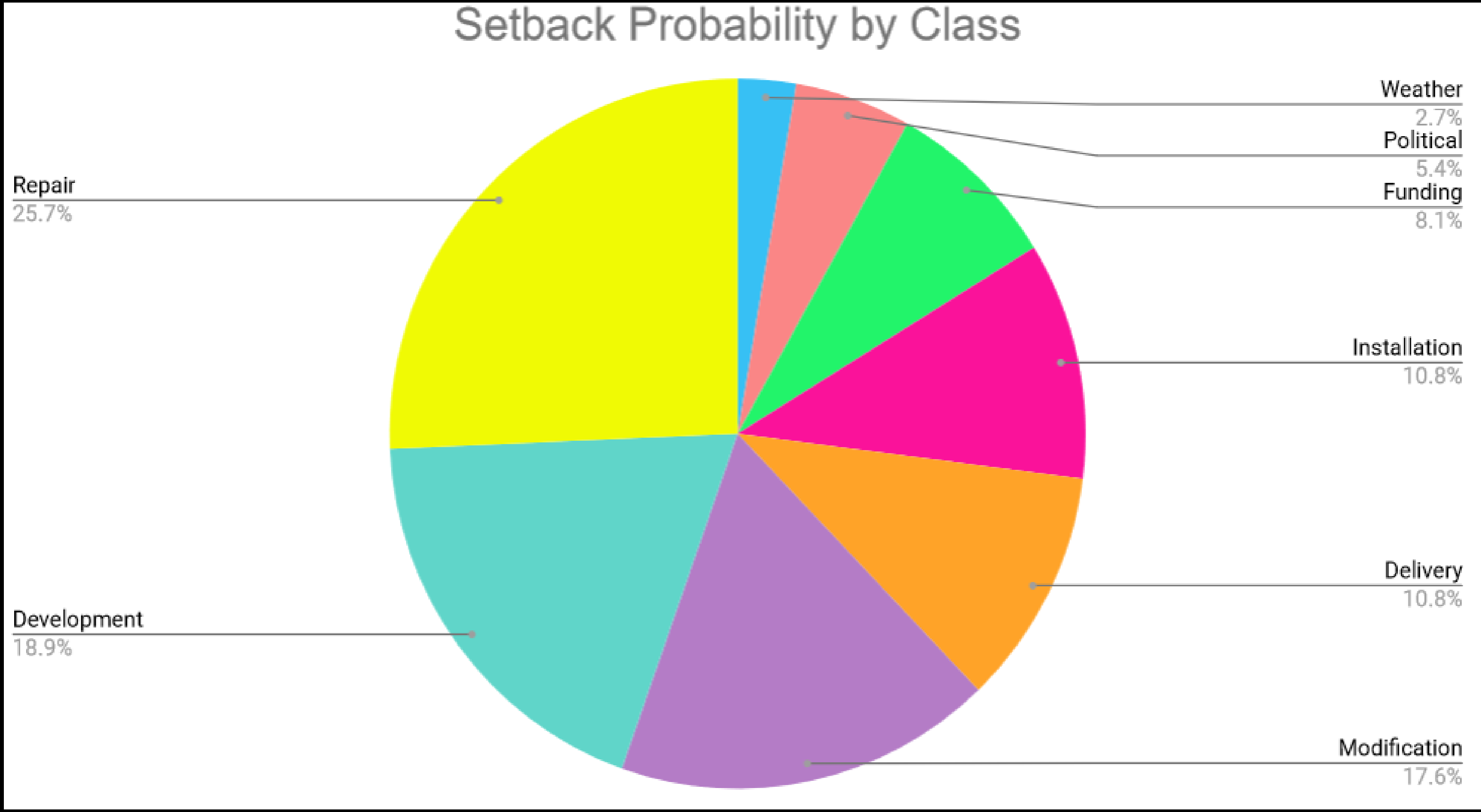
Setback Analysis

Further analysis of schedule setback data produced both an occurrence frequency percentage and an occurrence probability percentage for each setback class.

Setback Totals		Percentage of Programs in Which Setback Occurred		Probability of Setback Occurrence	
Setback Class	**Frequency of Occurence**	**Setback Class**	**Percentage of Occurence**	**Setback Class**	**Probability of Occurence**
Repairs	19	Repairs	48.72%	Repairs	25.68%
Installations	8	Installations	20.51%	Installations	10.81%
Development	14	Development	35.90%	Development	18.92%
Funding	6	Funding	15.38%	Funding	8.11%
Political	4	Poltical	10.26%	Poltical	5.41%
Delivery	8	Delivery	20.51%	Delivery	10.81%
Weather	2	Weather	5.13%	Weather	2.70%
Modifications	13	Modifications	33.33%	Modifications	17.57%
Average	**9.25**	**Average**	**23.72%**	**Average**	**12.50%**
Standard Deviation ±	**5.68**	**Standard Deviation** ±	**14.55%**	**Standard Deviation** ±	**7.67%**

Setback Analysis

Probability of occurrence for each setback class based on number of recorded schedule slips:



Phase Analysis

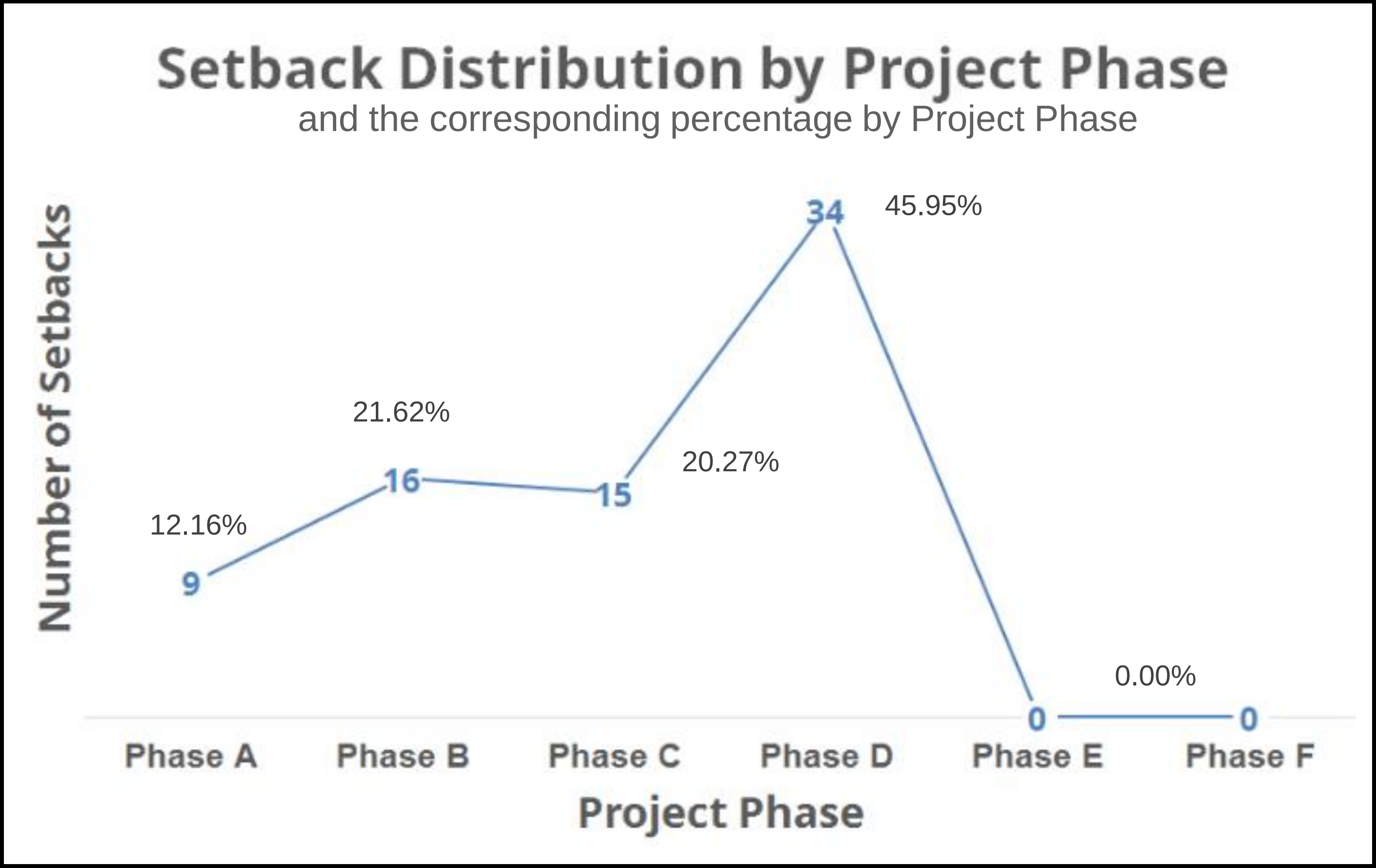
- Another form of analysis was to identify the project phase in which each of the 74 identified setbacks occurred.

- Official NASA phasing begins at Pre-Phase A and continues to Phases F.

- For this project, the start date of project development was mined from Phase-A activity due to information shortages.

Phase Analysis

Total number of setbacks in each project phase:



Phase Analysis

Breakdown of individual setback classes by phase:

Repairs	Phase A	0
	Phase B	0
	Phase C	3
	Phase D	16
	Phase E	0
	Phase F	0

Funding	Phase A	1
	Phase B	1
	Phase C	1
	Phase D	3
	Phase E	0
	Phase F	0

Installations	Phase A	0
	Phase B	2
	Phase C	3
	Phase D	3
	Phase E	0
	Phase F	0

Delivery	Phase A	2
	Phase B	4
	Phase C	0
	Phase D	2
	Phase E	0
	Phase F	0

Development	Phase A	5
	Phase B	4
	Phase C	2
	Phase D	3
	Phase E	0
	Phase F	0

Political	Phase A	1
	Phase B	3
	Phase C	0
	Phase D	0
	Phase E	0
	Phase F	0

Modifications	Phase A	0
	Phase B	2
	Phase C	6
	Phase D	5
	Phase E	0
	Phase F	0

Weather	Phase A	0
	Phase B	0
	Phase C	0
	Phase D	2
	Phase E	0
	Phase F	0

Cost Data

- The next task was to utilize the schedule slip analysis with program budgets.
- This research project aimed to determine the delta between a program's baseline budget and the total program cost.
- The delta between these two points is called the residual.

Cost Data

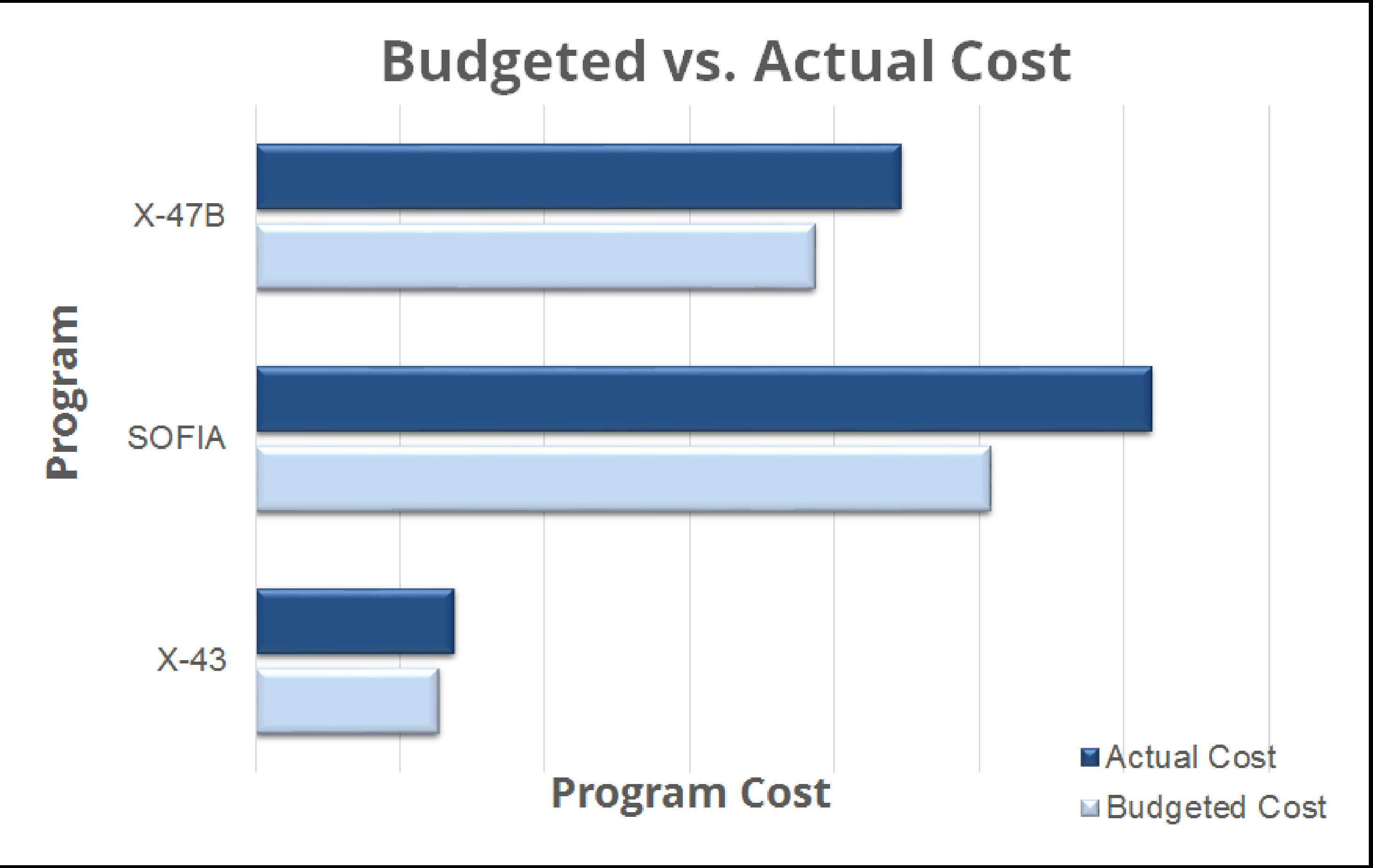
- Despite many interviews with past project managers and CFO accountants, only a few full-picture cost documents were obtained.

- Both baseline and actual budgets were only found for three aircraft: **X-43, X-47B,** and **SOFIA.**

- The costs were found through a combination of print and online research and personal interviews.

Cost Data

The proportional budgeted and actual cost for the programs in consideration for cost analysis:



Cost Analysis

- Every program experiences different difficulties and is unique in terms of objectives, schedules, and costs.

- Therefore, rather than simply considering the dollar value that a program overran, each of the residual values for X-43, X-47B, and SOFIA were converted to a **percentage of overrun** instead.

- As this project only had cost data for a few programs, there was an aim to eliminate the greatest possible amount of bias or skewed data.

Burn Rate & Residual Impact Formulas

- Calculate total-program burn rate

$$Total\ burn\ rate = \frac{Total\ Actual\ cost}{Total\ program\ lenght}$$

- Estimated residual impact of each setback class

$$Estimated\ residual\ impact\ of\ a\ setback\ class = Avg\ lenth\ of\ setback\ class\ *\ project\ burn\ rate$$

$$Setback\ \boldsymbol{Class\ Residuals}\ denoted\ of\ x\ from\ x1\ to\ x8$$

$$\boldsymbol{Total\ estimated\ residual\ impact = \sum_{i=1}^{8} Xi = x^1 + x^2 + \cdots + x^8}$$

- Setback class residuals denoted as values of $\boldsymbol{x}$ from $\boldsymbol{x^1}$ to $\boldsymbol{x^8}$

- Percentage breakdown of the estimated residual for each class

$$Setback\ class\ percent\ breakdown = \frac{Setback\ class\ residual\ impact}{Total\ residusal\ impact} * 100$$

Burn Rate Analysis

The process for <u>converting project residuals to percentage overruns</u> included the following steps:

1. A burn rate was calculated for each aircraft program by dividing the total program cost by the program length.

2. The estimated residual impact of each setback class was determined by multiplying the burn rate by the average duration of a setback class.

3. The total estimated residual impact for all schedule setback classes was determined by summing the classes' individual estimated residual impacts.

4. The percentage breakdown for each setback class was calculated by dividing the estimated residual impact value of each setback class by the total estimated residual impact of all setback classes.

Burn Rate Analysis

The process for converting estimated residual impacts to allocated residual values included the following steps:

1. The allocated residual values for each setback class were then found by multiplying the **actual** total residual of each aircraft by the residual percentage for each setback class.

2. The allocated residual amounts were then transformed to detail cost overrun as a percentage of the baseline by dividing the allocated residual of each setback class by the recorded baseline budget of a project.

3. Summing these percentages for all setback classes determines the total additional buffer percentage value that should have ideally been in place for the historical program.

Buffer Additional Percentage

- Averaging all of these additional buffer percentages from each project creates a general, historically-focused buffer percentage that could be added onto buffer reserves plans for future NASA programs.

- Based on these averages, each historic program analyzed should on average have had **15.54%** more management reserve in its budget.

NFRP Application

- In order to determine the suggested dollar increase to the NFRP management reserves, the suggested buffer addition percentage was multiplied by the NFRP baseline budget.

- When the estimated buffer addition was applied to the NFRP, calculations showed that project managers could consider adding at least **$19,769,156** in reserves to the program.

NFRP Application

The dollar increase was then broken down further to show the distribution of funds by setback class.

Setback	% of residual
Repairs	9.20%
Installations	9.22%
Development	24.83%
Funding	19.72%
Political	11.42%
Delivery	10.65%
Weather	2.59%
Modifications	12.37%

Setback Type	Residual Cost Breakdown
Repairs	$1,818,089
Installations	$1,822,193
Development	$4,908,431
Funding	$3,898,837
Political	$2,257,221
Delivery	$2,105,372
Weather	$513,005
Modifications	$2,446,007
	$19,769,156

Summary

- Because NASA programs often involve work that has never been attempted before, cost and schedule setbacks are common and should be appropriately planned for in projects.

- Every NASA program is different, and that should be taken into account when considering budget and schedule plans for new programs.

- NASA has extremely limited cost and schedule data available, which makes it difficult to analyze data trends or to learn from historical occurrences.

Questions

- steve.a.sterk@nasa.gov
- Telephone (661)-276-2377

Data Sources

- Armstrong’s Technical Reference Library
- *The X-Planes: X-1 to X-45* by Jay Miller
- Interviews with subject matter experts
  - Current NASA Project Managers
  - Former NASA Project Managers
  - NASA Accountants
- Government Accountability Office (GAO)
- Wikipedia and other online sources

Interviews

- Joel Sitz – X-43 data
- Dave Voracek – X-53 data
- Cheng Moua – X-56 data
- John Kelly – Dream Chaser data
- Patricia Daws – SOFIA data
- Darren Elliott – Risk calculations
- Josh Martin – Budget calculations
- Kerri Tannert – Cost data
- Karen Green – Cost data