PSAM 14

PROBABILISTIC SAFETY ASSESSMENT AND MANAGEMENT CONFERENCE
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AERONAUTICS AND AEROSPACE SESSION II

Synthesizing a New Launch Vehicle Failure Probability Based on Historical Flight Data

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Background and Motivation

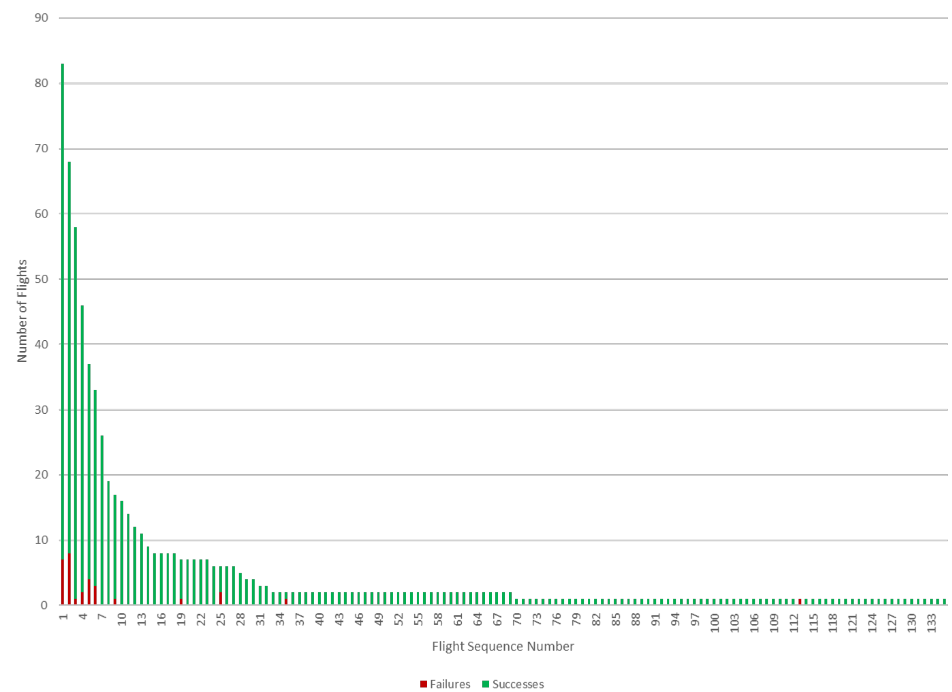
- New launch vehicles have historically had significantly higher failure probabilities in early flights than what has been predicted using Probabilistic Risk Assessment
- Work on a new methodology originally started with ARES I-X and Common Standards Working Group (CSWG) for range safety applications
  - CSWG consists of the Federal Aviation Administration (FAA), Air Force, and NASA
- Historical launch vehicle data was viewed as the best predictor of success/failure for launches of new vehicles.

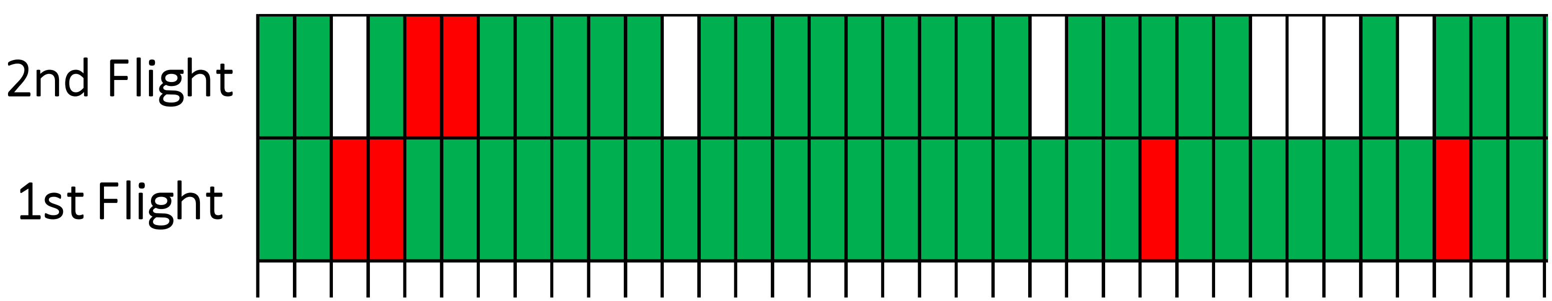
Database Description

- A launch vehicle database was developed that includes all launches from 1980 - 2017 (both US and foreign)
- Entries to the database include:
  - Vehicle by model type
  - Launch dates
  - Failure description
  - Failure Result (Loss Of Vehicle (LOV)/Loss Of Mission (LOM)
  - Failure cause (when available)
  - Vehicle designs (stages/engines/etc.)

Historical Launch Vehicle First Flight Risk

- Database was reviewed to determine launch outcomes by flight sequence number for each launch vehicle model





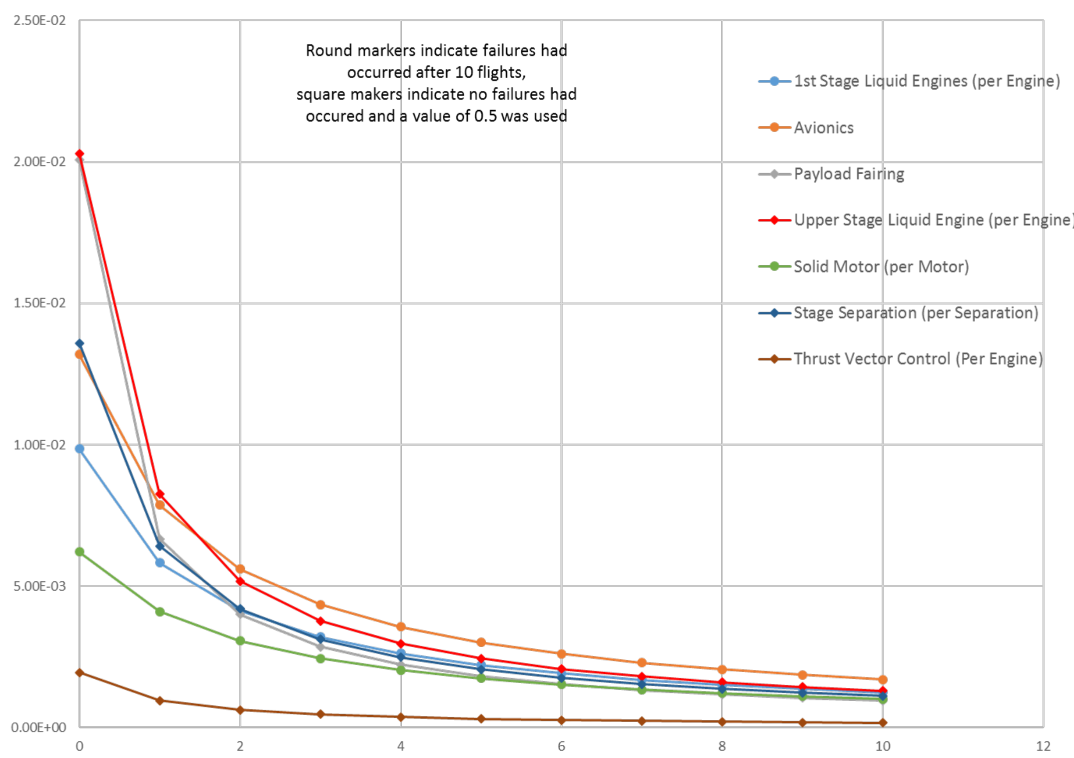
Design Element Failure Probability

- First two flights had similar, high, failure probabilities
- Table below shows failures by design element based on first two flights
- Number of elements flown is based on vehicle designs from the database

Design Element	Failures	Number of Design Elements Flown	Failure Probability per Design Element per Launch
Avionics	2	151	1.32E-02
1st Stage Liquid Engines	2	203	9.85E-03
Solid Propulsion	1	161	6.21E-03
Upper stage Liquid Engines	3	148	2.03E-02
Stage Separation	3	220	1.36E-02
Fairing Separation	3	149	2.01E-02
Thrust Vector Control	1	512	1.95E-03

Estimated Design Element Failure Probabilities by Flight Sequence Number

- Starting with the failure probabilities on previous page, the failure probabilities per element per launch by flight sequence number were estimated



Use of Data on a Hypothetical New Launch Vehicle

- A hypothetical vehicle was evaluated using the data
- The basic design assumed for the new vehicle is shown below

Basic Design Elements	
Number of Stages	2
Fairing Separations	1
1st Stage Design Elements	
Number of Liquid Engines	3
Number of Solid Motors	2
Upper Stage Design Elements	
Number of Liquid Engines	2

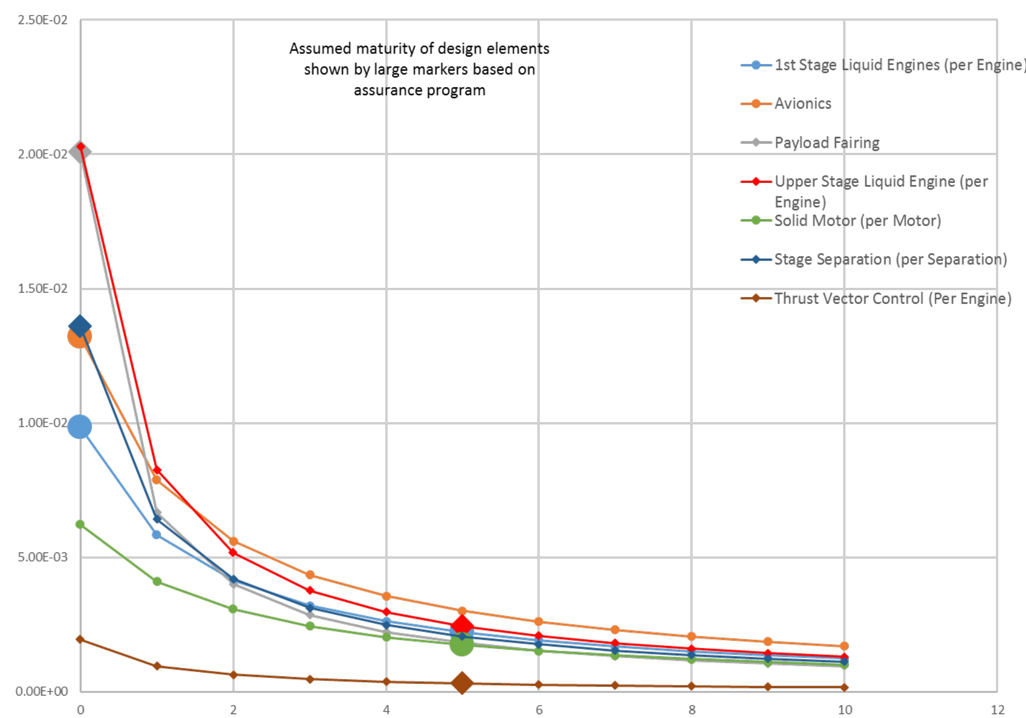
Probability of Failure based on Design and Empirical Estimates

- Based on the assumed design, the design element failure probabilities were found
- The estimated first flight failure probability is 0.134

Design Element	Design Element Failure Probability	# of Design Elements	Total Design Element Failure Probability
Avionics	1.32E-02	1	1.32E-02
1st Stage Liquid Engines	9.85E-03	3	2.93E-02
Solid Propulsion	6.21E-03	2	1.24E-02
Upper stage Liquid Engines	2.03E-02	2	4.01E-02
Stage Separation	1.36E-02	1	1.36E-02
Fairing Separation	2.01E-02	1	2.01E-02
Thrust Vector Control	1.95E-03	7	1.36E-02
Total			**1.34E-01**

Extending the Example to Account for the Assurance Program

- The previous example was extended to account for the assurance program
- Try to account for heritage hardware, extensive testing, etc.
- In the example assume credit is given to solid rocket motors, 2nd stage engines and thrust vector control.
  - Credit assurance equivalent of 5 flights



Example Result with Assurance Program Credit

- Crediting the 3 design elements with 5 flights each yields the below result
- The estimated failure probability per launch is reduced by 1/3.

Design Element	Design Element Failure Probability	Design Element Equivalent Experience	Total Design Element Failure Probability
Avionics	1.32E-02	0	1.32E-02
1st Stage Liquid Engines	9.85E-03	0	2.93E-02
Solid Propulsion	6.21E-03	5	3.47E-03
Upper stage Liquid Engines	2.03E-02	5	4.89E-03
Stage Separation	1.36E-02	0	1.36E-02
Fairing Separation	2.01E-02	0	2.01E-02
Thrust Vector Control	1.95E-03	5	8.73E-03
Total			**8.98E-02**

Conclusions

New launch vehicles have historically had a significantly higher average failure probability than mature launch vehicles, and PRA analyses do not adequately assess their failure probability. Assurance programs for launch vehicles have an impact on the success or failure probability of launch vehicles. By reviewing historical failures against assurance practices, greater confidence can be had for the first flight of a new vehicle and using this methodology can translate into a more accurate estimate of first flight failure probability and can be bridged into an existing PRA model.

Thank you for your attention!