Conditional Risk Investigations

COE CST Tenth Annual Technical Meeting

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October 30, 2020

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Prepared for:
Center of Excellence for Commercial
Space Transportation
Federal Aviation Administration

Center of Excellence for
Commercial Space Transportation

Outline

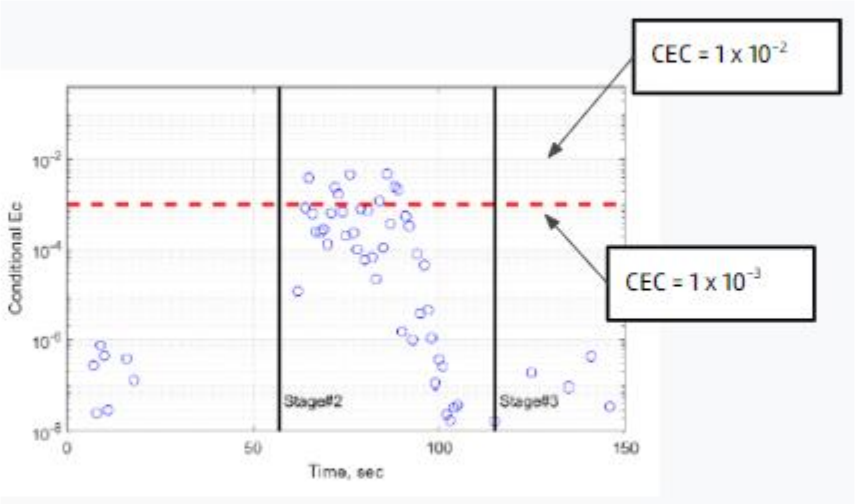
- Team Members
- Task Description and Goals
- Methodology
- Results
- Conclusions and Future Work

Team Members

- Wije Wathugala, Ph.D. , P.E.
  - Principal Investigator
  - Experimental Design
  - Analysis of final data
  - Project Management
- Steve Carbon, Ph.D.
  - Subject Matter Expert (SME) of high-fidelity risk analysis due to potential malfunctions of space vehicles and computation of Conditional Expected Casualty (CEC)
  - Setting up initial runs
- Tommy Lee, B.S.
  - Performed all the simulations and maintained the results database
- Erik Larson, Ph.D.
  - SME of Range Safety
  - Top level advice of project plans and ensured results are reasonable.
- Taylor Edwards, M.S.
  - Contract Manager
- Paul Wilde, Ph.D.
  - FAA Technical Monitor

Task Description and Goals

- FAA proposed using Conditional Expected Casualty (CEC) as a quantitative metric in the 450 regulation for:
  - Determining the need for flight abort with a reliable Flight Safety System (FSS)
  - Setting reliability standards for an FSS ('Gold Plated' vs 'Silver Plated' FSS)



- ARCTOS is tasked to continue computing CEC for past missions and investigating input parameters that affect those results.
  - Then develop guidance on how to compute CEC and the level of fidelity needed for input parameters to obtain conservative estimate of CEC.

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Calculating CEC

- Typical Steps in Computing CEC using High Fidelity Flight Safety Analysis (HFFSA):
  - Simulate failure trajectories at 0.1s intervals over the full flight duration
  - For each failure mode, perform large number of Monte Carlo simulations to capture various uncertainties
  - Propagate debris down to earth and compute expected casualty (Ec) for each state vector. That is equal to the Conditional Ec (CEC) for that state vector.
  - Then calculate CEC for one second duration for each failure mode by
  - $CEC_{N_{sv}} = \sum_{i=1}^{i=N_{sv}} (Pf_i \times CEC_i) \Big/ \sum_{i=1}^{i=N_{sv}} (Pf_i)$
    - Pf_i is the probability of i[th] state vector and
    - $CEC_{N_{sv}}$ *is the CEC for all* N_{sv} state vectors in one second duration.
- There are many input parameters to HFFSA that are uncertain. How they affect the computed value is the topic of this research.

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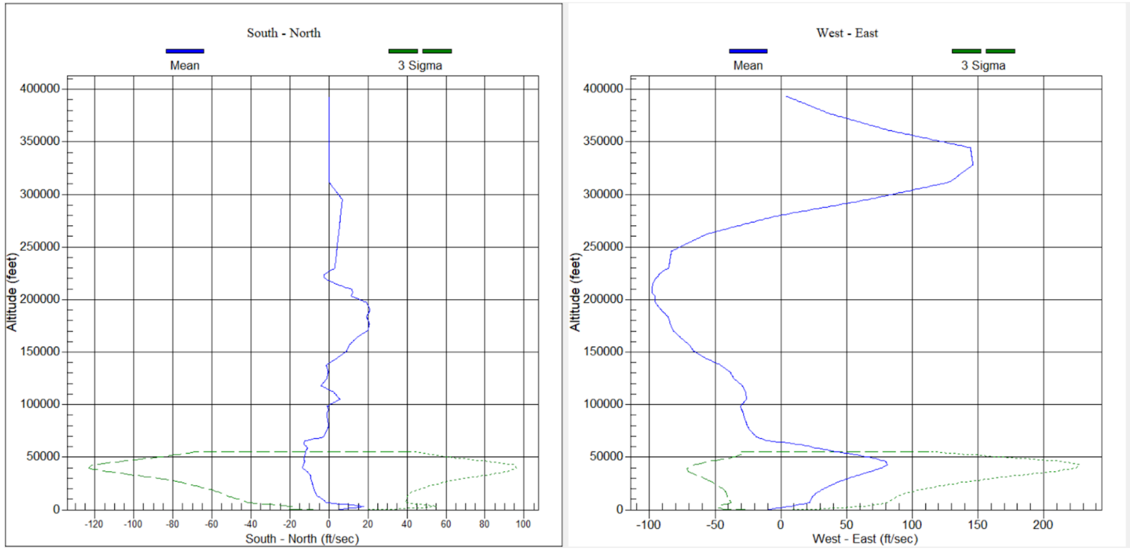
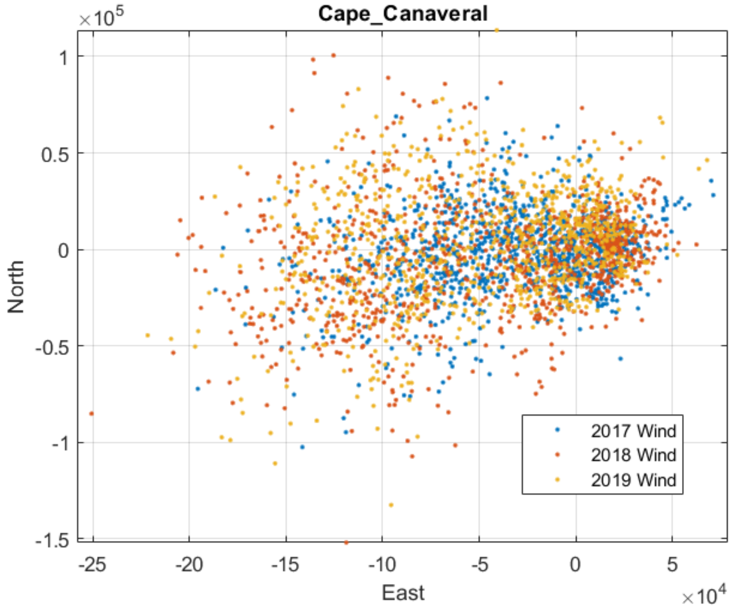
Input Parameters That Affect CEC

- Debris Catalogue
  - Assumed debris mass distribution at breakup
  - Assumed imparted velocities of these debris at break up
- Wind profile
  - Debris propagation via atmosphere is affected by the assumed wind profile at breakup point until they reach ground.
- Population models
  - Time of the day
  - Fidelity of the population model
  - Licensed version of Landscan vs public domain Gridded Population of the World (GPW)
  - Sheltering Distribution
- Aero breakup threshold of the rocket
  - Q-alpha is the maximum aero load a rocket can take before they break.
- Number of Monte Carlo Samples used per second
- Before we can study the effect of these input parameters, it is necessary to parameterize them.
  - It is not straight forward since all these input parameters are complex and their effects are complex too.
  - In the next slides we will present how we studied the wind uncertainty to give you an idea of the thinking process

Parameterizing Wind Uncertainty

- Typical wind profile over altitude near Cape Canaveral, FL is given to the right.
  - Wind profile changes with weather and season.
- How can we rank order the effect of these wind profiles on CEC in order to estimate the maximum effect?
- We developed a 2D parameter that is related to the drift of a debris due to wind
  - In this case, we assumed the debris is falling at its terminal velocity in the atmosphere and calculated the drift due to a given wind.
  - This results in a 2D vector that can be parameterized as two numbers (East and West).





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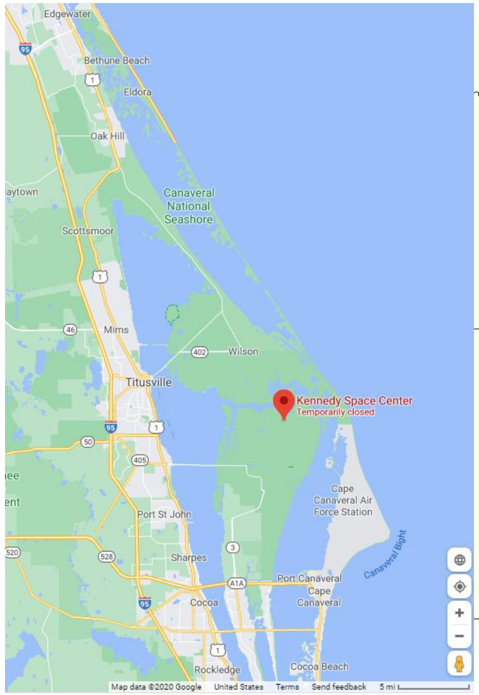
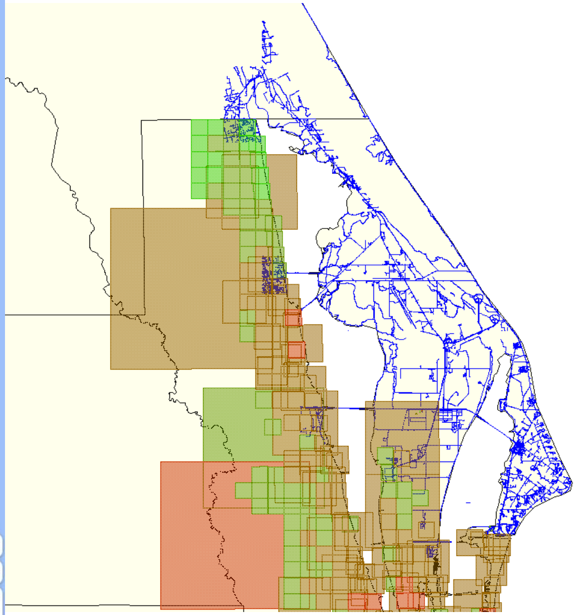
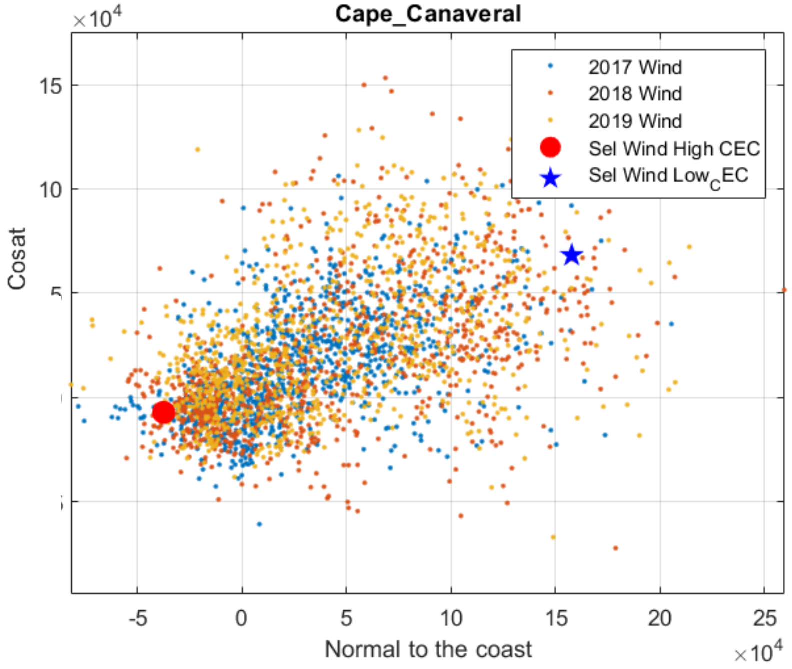
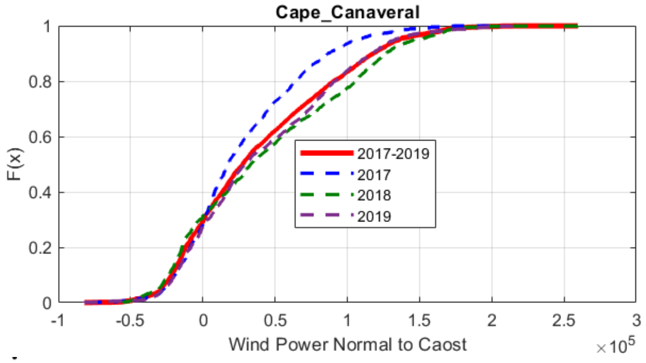
Parameterizing Wind Uncertainty

- Uncontrolled population centers during a launch are shown into the right.
- Wind that generally move debris towards land would tends to increase the expected casualties.
  - We transformed the wind power to normal to the cost and along the cost.
  - CDF of wind power normal to the coast is used to select suitable wind profiles for High and Low wind power values for the factorial design
  - We selected 2.5% and 97.5% percentile winds and they are marked in t he figure.









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Methodology

- Selected critical time slices from various representative missions
  - Eight vehicles
  - Ascending rockets, stage returns, and capsule returns
  - Three launch pads
    - Cape Canaveral, Florida
    - Wallops, Maryland
    - Vandenburg Air Force Base, California
- Used Design of Experiment (DoE) methods to decide how to vary each input parameter for these simulations.
  - Used partial factorial designs
  - Performed 166 RRAT simulations (Exploratory and DoE runs)
- Analysis of the results are in progress

Results

- Conditional risk studies projects at ARCTOS has resulted in two reports so far.
- It also contributed to the development of a FAA Advisory Circular on High Consequence Modelling
- When the study is complete by the end of this year
  - We will present results to the community via
    - Final report
    - A Journal paper
    - Presentation at RSG meeting on Nov 11, 2020

Conclusions and Future Work

- ARCTOS R&D work on Conditional Expected Casualty (CEC) has led to following conclusion so far.
  - CEC is a good metric that can be used to quantitatively determine the need for a Flight Safety System (FSS) to reduce casualties from high consequence events.
  - Draft method to satisfy FAA criteria for CEC using statistical methods
- Next Steps
  - Complete data analyses
  - Present the effect of input parameters on computed CEC to the community
  - Develop guidelines for computing CEC considering the level of uncertainty from various input parameters