Reliability, Availability and Maintainability
for Crew Survival Analysis Methodology

RAM for CSAM

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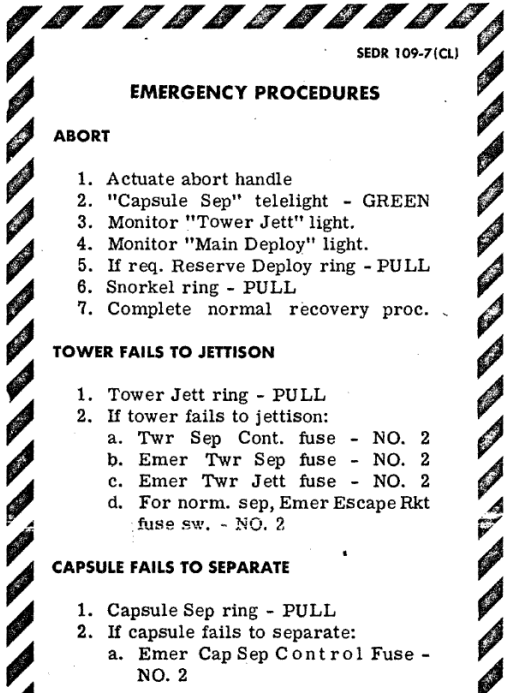
Contents

Notional Crew Survival Scenario

- Plane Crash over the Pacific (Ref. Castaway)
  - Scenario Description:
    - A plane has experienced engine trouble and is unable to maintain altitude and crash lands into the pacific ocean near a remote island. Half of the passengers and flight crew survive the crash landing and make it to life rafts and island. Search and Rescue has been activated, but survivors must survive no less than a month with the resources they crashed with.
  - Current Crew Survival Methods:
    - Short term 7-day survival kit (food, water, signal, navigation, and shelter equipment)
  - Possible additional Crew (crew + passengers) Survival Methods that could be implemented (discussed in future slides)

History of Crew Survival at NASA

- NASA has always implemented crew survival methods (CSM) since the Mercury Program. These CSMs were simply called Emergency Procedures and were not thoroughly defined.
- The Idea for what is now known as a Crew Survival Analysis Report (CSAR) emerged after the Columbia Incident.
    - Space Shuttle Program charted the Spacecraft Crew Survival Integrated Investigation Team (SCSIIT).
        - This team preformed comprehensive analysis of the accident focusing on factors and events affecting crew survival and developed recommendations for improving crew survival for all future human space flight vehicles.
        - SCSIIT investigated all elements of crew survival, including the design features, equipment, training and procedures intended to protect the crew.
        - The team's report provided recommendations to NASA for possible incorporation into future crewed space vehicle designs based on the results of that investigation.
- CSARs are required to satisfy NASA human rating requirements and are part of the Human Rating Certification Package (HRCP) for all crewed space vehicles developed or procured by NASA to human rate spacecraft for crew habitation and satisfy human rating requirements.
- Currently, NASA is developing CSARs for the Artemis Lunar Missions.



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EMERGENCY PROCEDURES

ABORT

1. Actuate abort handle
2. "Capsule Sep" telelight - GREEN
3. Monitor "Tower Jett" light.
4. Monitor "Main Deploy" light.
5. If req. Reserve Deploy ring - PULL
6. Snorkel ring - PULL
7. Complete normal recovery proc.

TOWER FAILS TO JETTISON

1. Tower Jett ring - PULL
2. If tower fails to jettison:
   a. Twr Sep Cont. fuse - NO. 2
   b. Emer Twr Sep fuse - NO. 2
   c. Emer Twr Jett fuse - NO. 2
   d. For norm. sep, Emer Escape Rkt fuse sw. - NO. 2

CAPSULE FAILS TO SEPARATE

1. Capsule Sep ring - PULL
2. If capsule fails to separate:
   a. Emer Cap Sep Control Fuse - NO. 2

Project Mercury Capsule Flight Operations Manual, Capsule 7

Crew Survival Analysis Definition and Approach

- Crew survival analysis is the assessment of the ability for the crew to survive catastrophic events and return safely to Earth.
- Crew survival analysis is how human mission development organizations evaluate when the crew may be saved, determines the functionality necessary to affect their survival, and assists leadership with risk-informed decision making for including or excluding crew survival capabilities and the appropriate level of design or mission certification necessary
- Although the goal of crew survival is to provide survival capabilities for all catastrophic events, NASA recognizes that not all catastrophic events are inherently survivable, nor do all recommendations improve the crew's chances of survival enough to warrant expending additional resources

Required Data Inputs to Conduct Analysis

- Analysis utilizes data from but not limited to:
  - Program Requirements
  - Concept of Operations
  - System Design and Architecture
  - System functions/capabilities
  - Hazard Reports (vehicle, payloads, etc.)
    - Entails vehicle hazards and Crew Survival Methods
  - FMECA, FMEA/CIL
  - Reliability Predictions, Probabilistic Risk Assessment
  - Limited Life, Availability and Maintainability Analysis
  - Contingency Scenarios
  - Planned contingency responses

Generic Crew Survival Analysis Process

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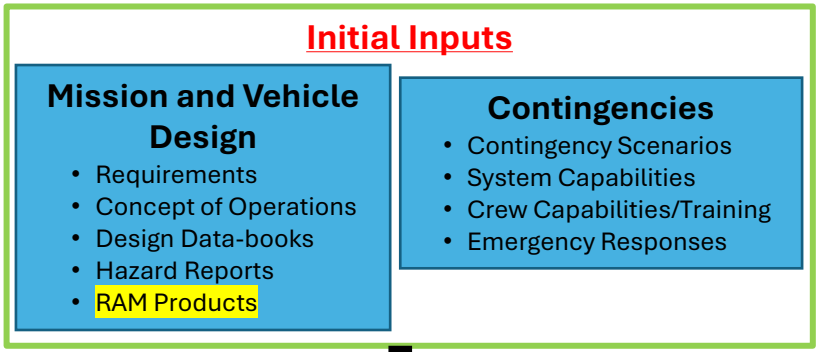

Crew Survival Analysis Report

Preform Crew Survival Analysis on Vehicle / Mission to develop Coverage Map(s) to Identify

Crew Survival Capability Exists
(Sufficient data proving that a crew survival method (CSM) is available and effective for the analyzed scenario)

Crew Survival Capability May Exist
(A CSM is available and may be effective, but not guaranteed to save crew due to time to effect or scenario specific conditions)

Crew Survival Does not Exist
(There is no available or effective CSM in place to save the crew, a loss of crew will occur

Program Reviews and Approves Analysis & Results

Scenarios Where Crew Survival Does Not Exist are Prioritized With Potential Mitigation Options Evaluated

Program Manager Decision

Accept the Risk	Accept Recommend Mitigation	TBD More Data Needed
Significant Program Impacts to mitigate* or No CSM exist	Feasible CSM exist to mitigate* hazard effects and save the crew	Insufficient Design Maturity / Con-Ops

Gap research and mitigation and implementation occur through tiger teams, contract mods, etc.

Generic Crew Survival Coverage Map

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Crew Survival Response to Hazards by Mission Phases		Mission Phases	Initial Orbital Operations			
		Mission Sub-Phases (Not to Scale)	Docking Vehicles Proximity Operations	Hard Docking Complete	Docking Vestibule Pressurization	Docking Hatches Open
Crew Survival Assessment Key:		Vehicle Configuration	Chaser Vehicle xx km from Target	Chaser and Target Vehicle Docked	Chaser and Target Vehicle Vestibule Pressurized	Chaser and Target Vehicle Docking Hatches Opened
Crew Survival Method Exist and is highly Available and Effective						
Crew Survival Method is Available and Effective, but scenario occurrence can lead to a *Loss of Crew if certain conditions exist*						
No Crew Survival Method - Loss of Crew						
NA - Not Applicable during this mission phase						
Crew Survival Scenario	**Crew Survival Scenario Cause(s)**					
Scenario title identified by name	Causes leading to scenario occurrence identified and inserted into rows to be analysed		Example **Abort Docking Attempt** **If the docking or target vehicle experience an automated docking error, the docking vehicle can abort the docking attempt and back away to a safe distance.**	Example **Abort Docking Attempt** **The docking vehicle crew can abort the docking attempt and back away to a safe distance if hard docking has not completed.**	Example **If the vestibule is unable to pressure to enable crew transfer, scenario occurrence will result in a Loss of Crew**	**N/A** **Automated docking systems are not utilized for hatch removal**

Crew Survival Coverage Map and Scenario Classifications

- Per the CAIB report, crew survival analysis is intended to be a companion to the program and mission life cycles. Crew survival analysis cannot eliminate all risk from a mission, it can only inform management so they may make decisions about design and operations development informed by understanding underlying risks.
- All crew survival scenarios will eventually fall into one of three classifications:
  1. Scenarios with CSMs available to save the crew, and there is high confidence that the crew can survive the event.
  2. Scenarios with CSMs available, but the methods may not be reliable or effective under all circumstances.
  3. **Scenarios for which there are no CSMs available.**

Notional Castaway Plane Crash Coverages Map Summary

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Hazard	Method	Availability x Effeteness	Color Catagory
Plane crash impact	None	0 x 0	Red
Injury	Basic Survival Kit	1 x 2	**Yellow**
Elements (weather and nature)	Basic Survival Kit	1 x 2	**Yellow**
Dehydration	None	0 x 0	**Red**
Malnourishment	None	0 x 0	**Red**

Existence of survival gaps leads to feasible survival methods research

Notional Crew Survival Scenario

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  - Current Crew Survival Methods:
    - Short term 7-day survival kit (food, water, signal, navigation, and shelter equipment)
  - Possible Crew Survival Methods that could be implemented:
    - Crew Cabin Ejection Mechanism
    - Parachutes for each person
    - Advanced Survival kit 30+ days (food, water, signal, navigation, emergency shelter)
    - Trauma Kit for basic to severe injuries
    - Sustaining kit (hunting and fishing equipment, wood craft tools, solar still)

Crew Survival Gap Prioritization Process (Quantitative)

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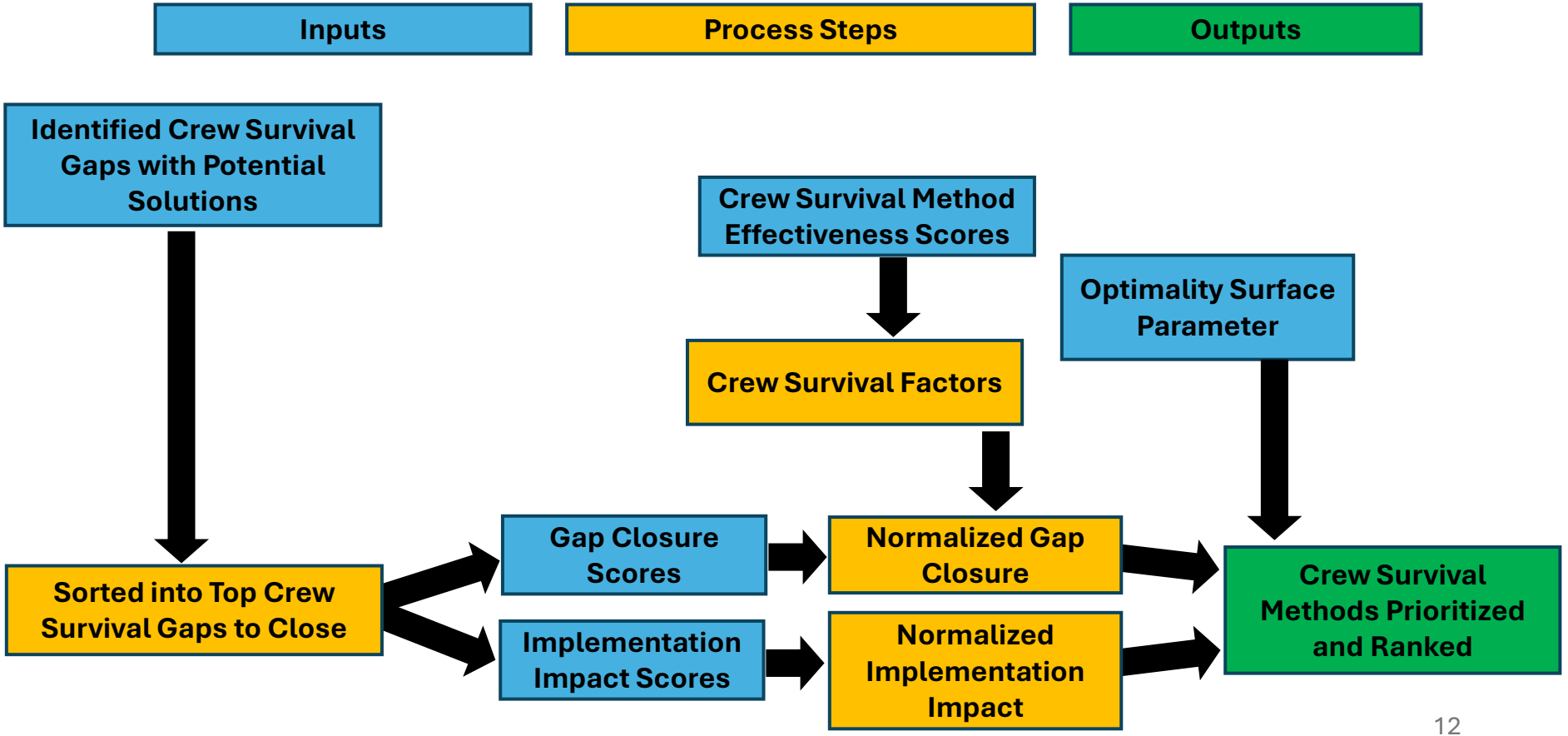

Prioritization Process Parameters

- Gap Scores (How bad is the Hazard)
- Implementation Impact Scores (Cost/Risk of implementation)
- Survival Factors (Components to the Probability of Survival)
  - Ideal Effectiveness
  - Availability
  - Reliability
- Optimality Surface Parameter (Characterization of program risk posture)

Notional Example Scenario Matrix

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						Impact Score	5	3	1	2	4			
Survival Scenario #	Scenario Survival Probability			**Hazard \ Method**			Cabin Ejection	Personal Parachutes	Advanced Survival Kit	Trauma Kit	Sustaining Kit			
1	0.72		Gap Score				M1	M2	M3	M4	M5	Count	Hazard Survival	Normalized Gap Closure
2	0.432		5	Crash Impact		H1	1	2				2	0.84096	0.84096
3	0.09		4	Injuries		H2	3	4		5	6	4	0.65150675	0.5212054
4	0.072		3	Weather Elements		H3	7	8	9		10	4	0.94666224	0.567997343
5	0.504		4	Dehydration		H4			11		12	2	0.698432	0.5587456
6	0.168		2	Malnurishment		H5			13		14	2	0.698432	0.2793728
7	0.729					Count	3	3	3	1	4			
8	0.486					Method Gap Closure	0.792	0.5	0.562	0.315	0.599			
9	0.315					Normalized Impact	1	0.6	0.2	0.4	0.8			
10	0.441													
11	0.504													
12	0.392													
13	0.504													
14	0.392													

Prioritization Process Notional Results: Optimality Surface Plot

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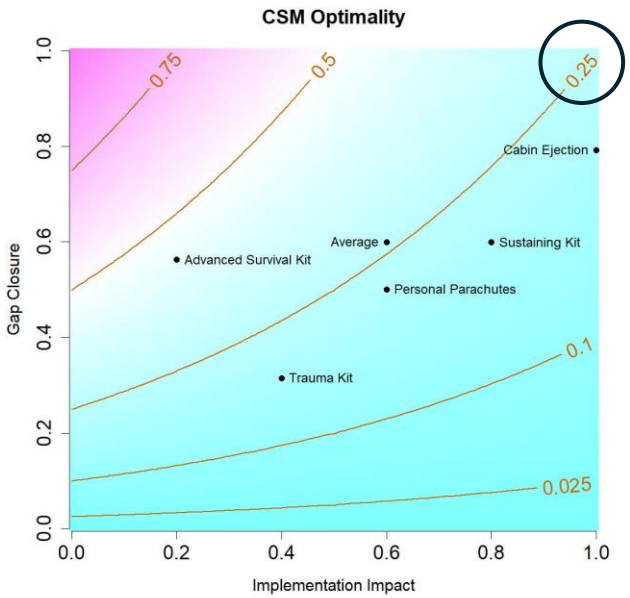
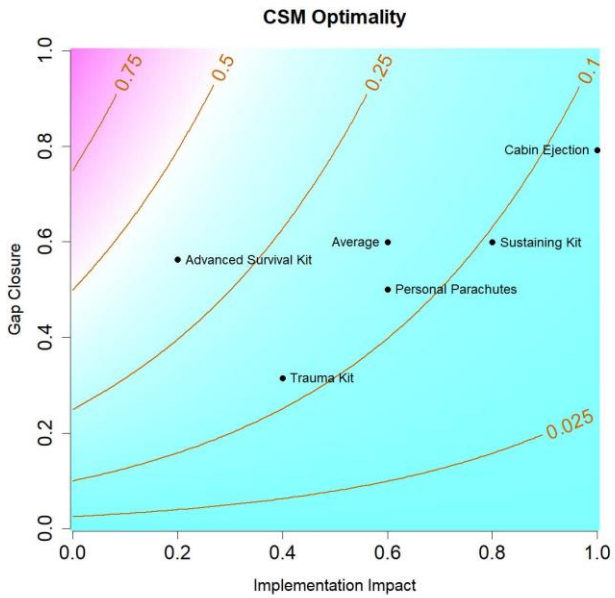
Optimality Model Surface Equation: $O \stackrel{\text{def}}{=} \frac{G_c}{(1/s)^I}$

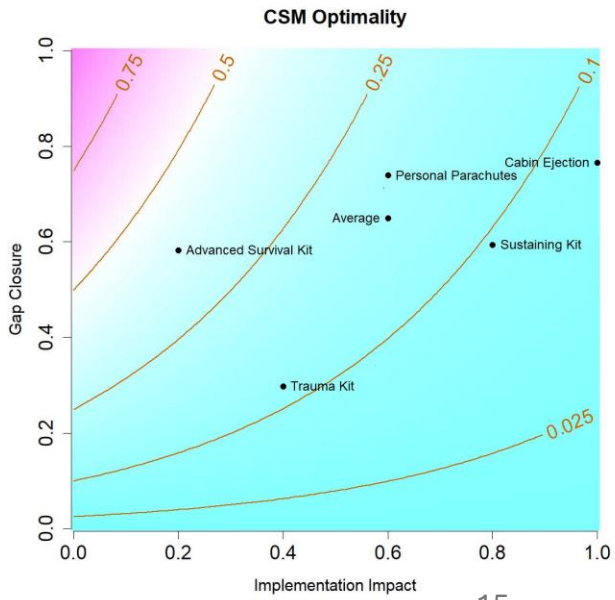
Preliminary S = 0.25



Baseline S = 0.1



Baseline S and Design Progress



Conclusion; What Do Programs do With Prioritized Results?

- What programs do with results, how the list of prioritized methods is used.
- Qualitative:
  - Design cycles decisions:
    - accept risk
    - research
    - implement
- Quantitative: analyze concurrent with the design for
  - Risk characterization
  - Reprioritization
  - Trending crew survival analysis progress metrics


ANY QUESTIONS?
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Notional Crew Survival Reporting & Recording Results

- Reporting/Recording Crew Survival results include:

1. The status of each scenario analyzed
   a. A description of the scenario, including its extent and time to effect considerations
   b. An explanation regarding how the scenario does or does not close
   c. A description of available crew survival methods, including any caveats or limitations
   d. A characterization of the current remaining risk to loss of crew. This will be documented in words and graphically using the Crew Survival Method Coverage Rating matrix
2. Recommendations for new crew survival methods or enhancements to existing ones based on RAM prioritization process results
3. A recommendation on whether to accept the scenario occurrence and risk or continue analysis
4. A plan for further analysis or monitoring development, as applicable
5. A schedule to return with decision packages, based on management direction

- Final results for each mission will be recorded in a mission Crew Survival Analysis Report, which provides the overall crew survival posture. Integrated scenarios will be fully documented, including recommendations and decision packages, to provide history and context