Martin-Baker

Modelling and Integration of Survivability A 6DOF Tool in the HSI Domain

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Contents

Human Systems Integration

Human Systems Integration (HSI) and Domains

- Human Systems Integration
  - Definitions vary between organisations
  - A philosophy, an approach to/part of Systems Engineering, a set of processes, or a goal
- In common, is that HSI covers:
  - A) Humans/People
    - Users AND those who manage, maintain and support
  - B) Hardware/Software/Technology
    - The "traditional" view of the system
  - C) The interfaces between A and B
    - Whether it be through Input/Output, processes, or the environment in which the system operates
- Domains are used to break the discipline of HSI into functional areas, examples from the MOD, USAF, and NASA are shown

MOD

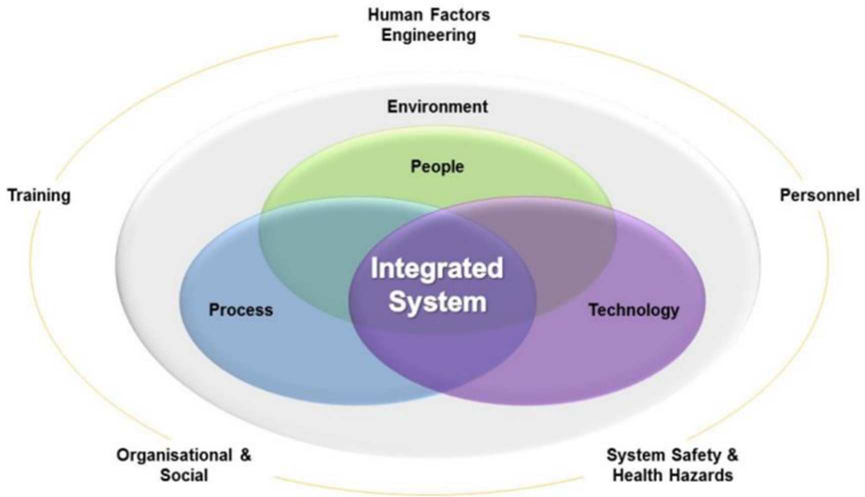


Figure 2: HFI Domains

Figure 14: HSI Integrates the Domains

USAF

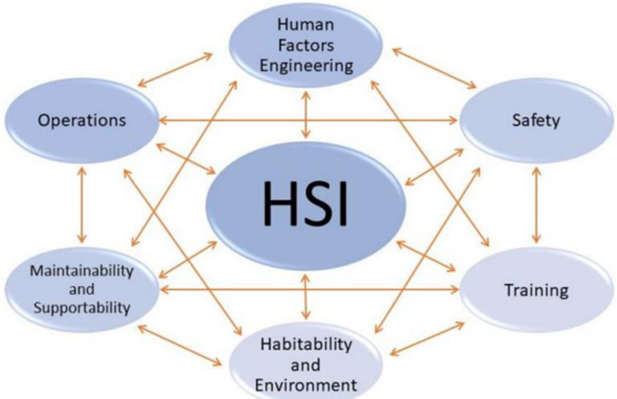


Figure 2.2-1. Sample 2-way Interactions Among NASA HSI Domains

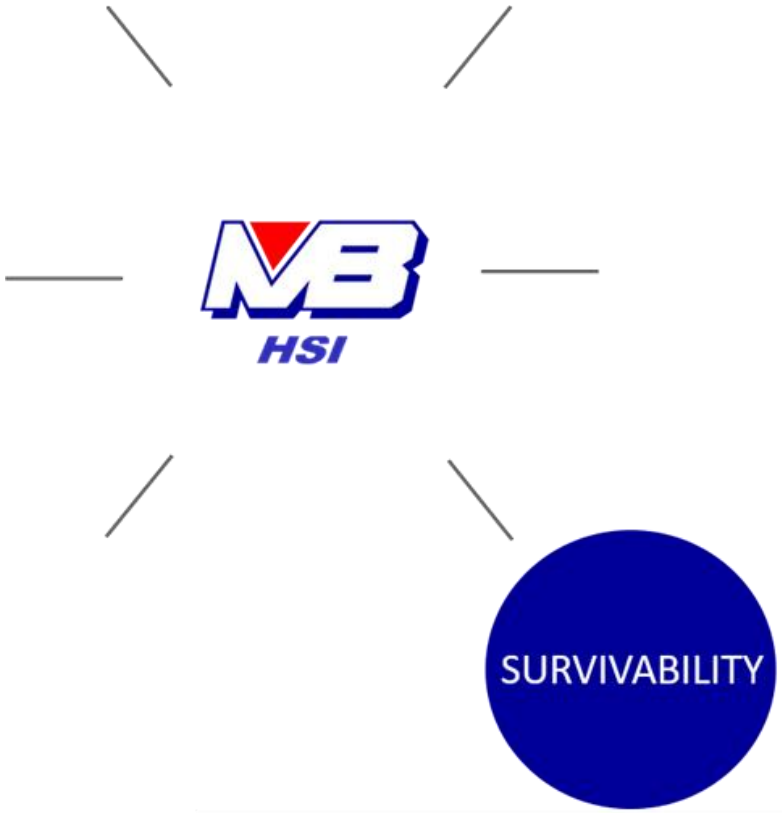
NASA

HSI at Martin-Baker

- Martin-Baker has defined 6 HSI Domains
  - Adapted for Escape Systems
- Optimal aircraft system performance requires human operator peak performance
  - Even more important in 6th gen aircraft
  - As the human has a battlespace commander role over and above the aircrew role
- Given the prime interface between the human and the escape system, enhanced integration with human-centric view (i.e. HSI) is a rapidly emerging focus area
- Safety and Survivability domains are still the core of the Escape System

The Survivability Domain

- Survivability is the functional area where the emergency escape capability fits in the MBA HSI model
- Essential to be able to model performance and analyse success of the escape system
- Which tools are available to perform analyses in the Survivability domain?
- What kind of results can be obtained and what can we learn from the findings?
- How is the integration of escape systems with the aircraft affecting the integration of the human with the aircraft?

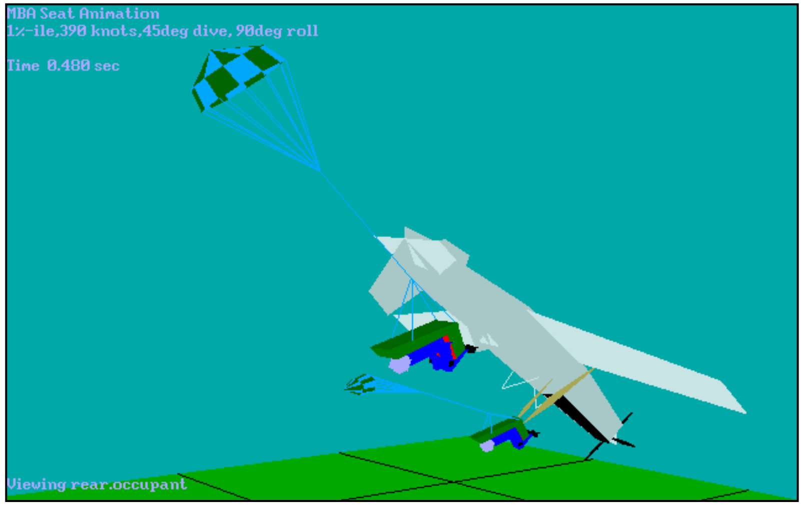


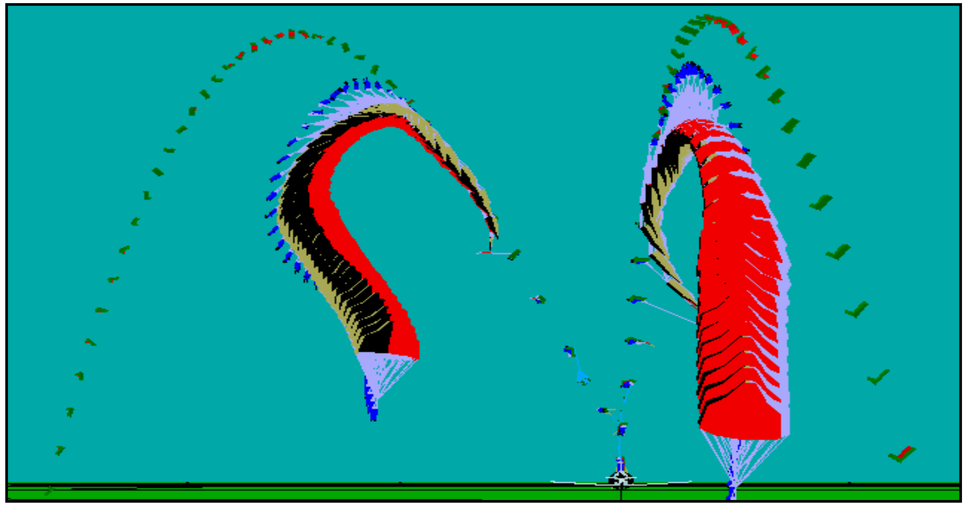
The design and development of systems that enhance mission capability and survivability through **normal operations** but also in the instance of **emergency escape**. The ability of our products to enable their operators to withstand hostile, hazardous environments, without aborting operations or suffering illness, disability, or death, through the **integration of protective and life support equipment.**

Seat6d: The MBA 6DOF Escape System Tool

Seat6d History

- Seat6d was started in 1994
- Written in C++ using Object-Orientated Design
  - Presented at SAFE 1996 – Object-Orientated Ejection Seat Model
  - Again at SAFE 2019 – Escape System Performance and Injury Metrics Modelling
- Still very much in use 25+ years later
- Validated many times over against test data
- Accredited by JSFPO on F-35 programme
  - Amongst others





Seat6d Uses

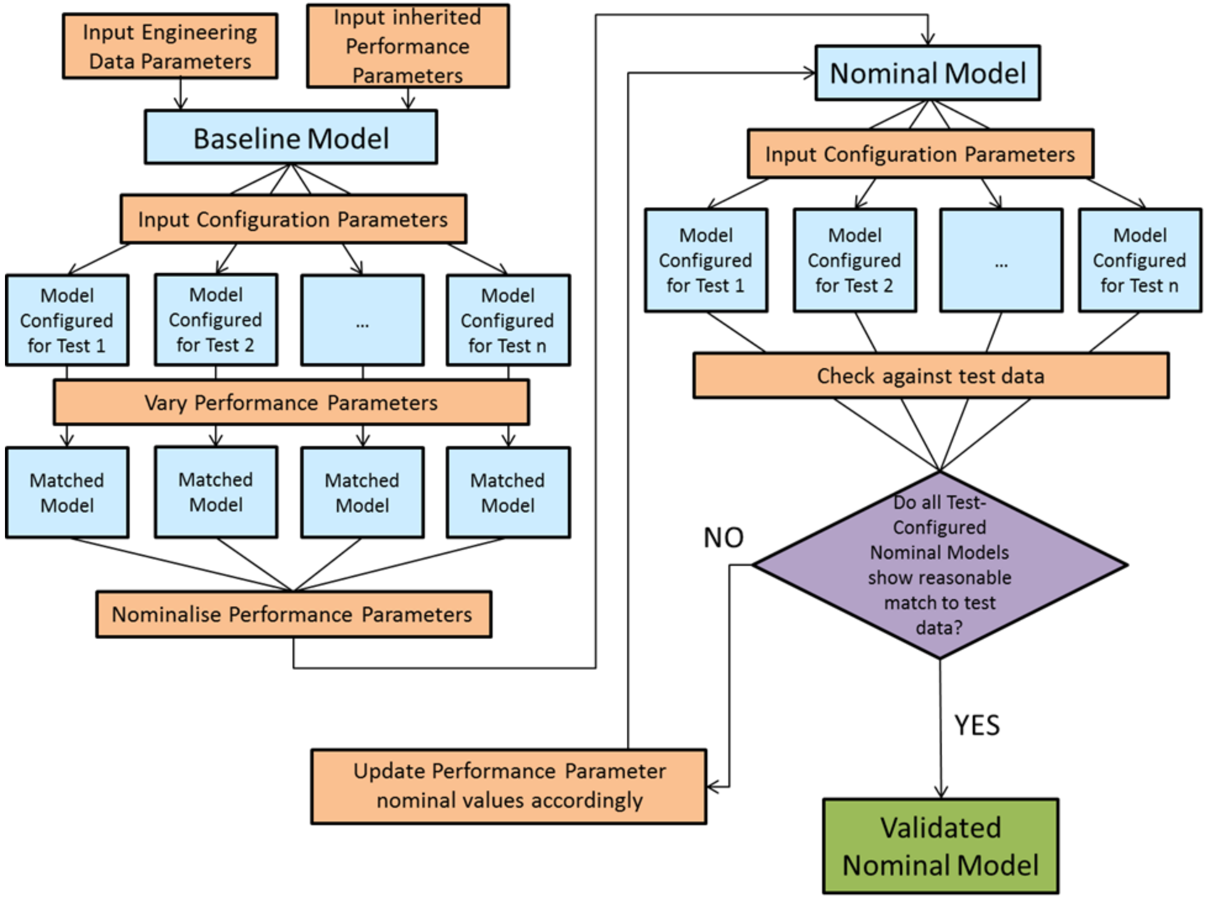
- Performance Predictions
- Test prediction and analysis
  - Tests also validate models
- System Design/Trade Studies
  - Simulate yet-to-be built configurations or mix/match existing components
  - Support to proposals
- **Mishap investigations**
  - Can import aircraft black-box data to drive aircraft model
- Support to Seat Requirement Verification
  - MDRC, chest g's, fin clearance and terrain clearance etc.
- Derivation of sub-system design limits
- Crew Manual data
- **Running against historical database of ejections**
  - ~4000 live ejections where ejection conditions known
  - Ref. SAFE 2014 – Ejection Success Prediction Based On Historical Data

Seat6d Example

- Harrier II GR.7 ejection – Mk12H
- Lowestoft Air Show – 2nd August 2002
- Pilot safely ejected – Minor ankle injury from landing back on the aircraft

Model Evolution & Validation Process

- Baseline model inputs
  - Engineering data parameters
  - Inherited performance parameters
- Test matching
  - Input configuration parameters
  - Vary performance parameters
  - Match phase-by-phase
- Generate nominal model
  - Review matched parameters over the test campaign
    - Systemic factors → Baseline update
    - Random factors → Monte-Carlo
    - Anomalies → Consider discarding
- Check performance against test data
- With reasonable matches, nominal model has been validated, and can be used for analysis

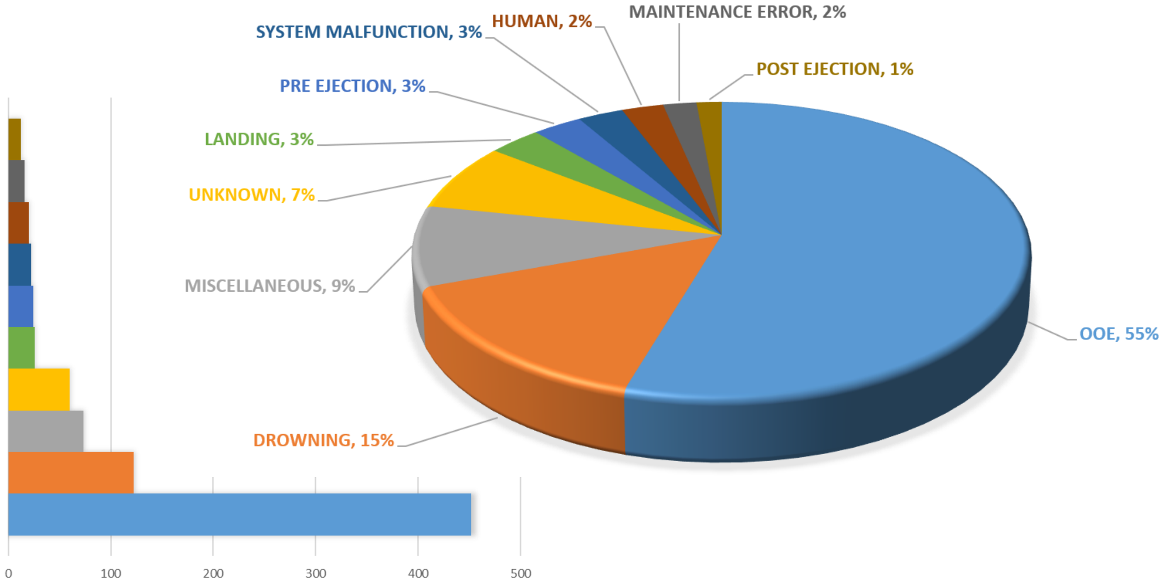


Survivability and Out Of Envelope (OOE) Ejections

OOE Analysis: Background

All ejection Seats

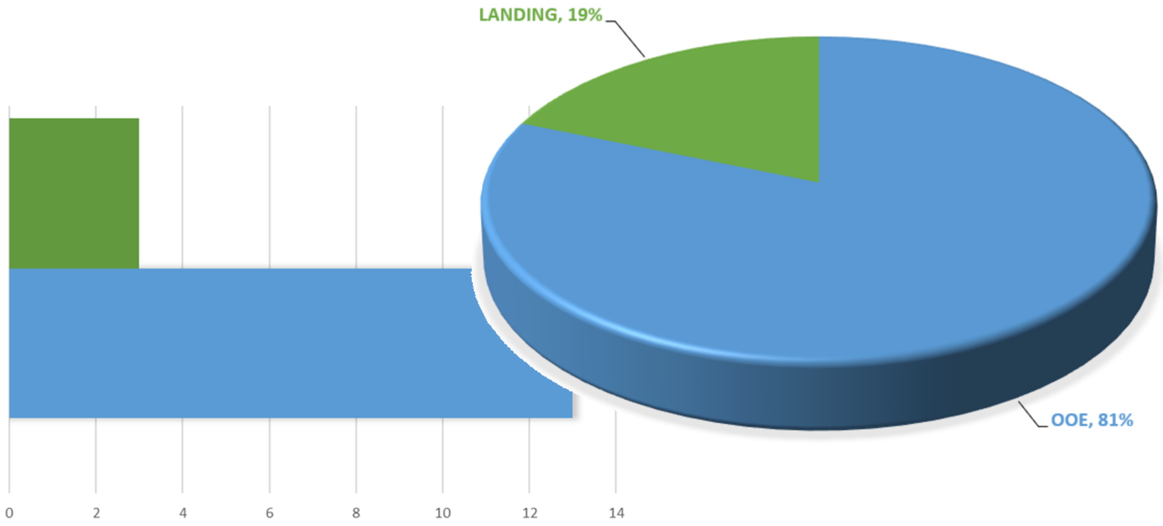
- **830** fatalities / **8472** ejections
- Majority of recorded fatalities caused by **Out Of Envelope (OOE)** escape – 55%
- Significant proportion of fatalities caused by **Drowning** (historically – until early 90s)
- Other fatality causes do not appear to be major drivers



Modern Ejection Seats

- **13** fatalities / **235** ejections
- Majority of recorded fatalities caused by **Out Of Envelope (OOE)** escape – 81%
- Significant proportion of fatalities caused by **Landing** (total of 3 – all with torso harness)
  - Possibly due to difficulty in releasing torso harness parachute fittings

NOTE: Relatively wide 90% CIs due to low incidence of fatalities for modern CES



OOE Analysis: Methodology

- We have established that **OOE is the major cause of fatality** in ejections
  - Both historically and with modern ejection seats

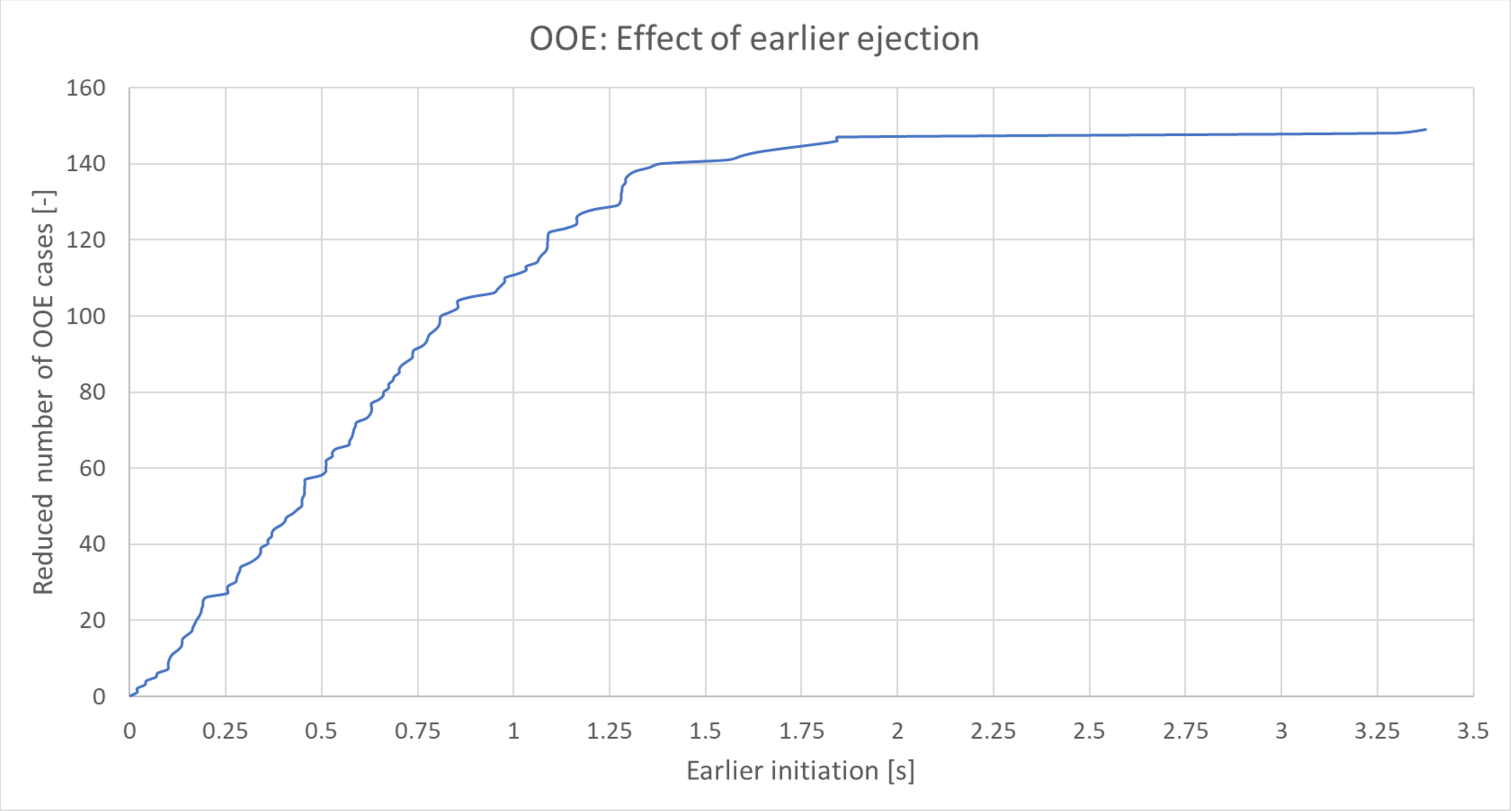
- Need to understand the **extent and severity** of OOE ejections
  - How close were they to being in envelope and thus more survivable?

- The **historical database of ejections** can be used for this analysis
  - 1. Utilise low level ejections for efficiency
    - 1922 runs instead of ~4000
  - 2. Select a modern ejection seat
    - In this case the **US16E** for F-35
  - 3. Assess how many runs would not have resulted in a safe ejection
    - 173 runs, thus the **rate of safe conditions is 91%** against historical ejections
      - It is below the 94.5% success rate for modern seats as the rate of safe conditions could include OOEs that were not fatalities
  - 4. For those that did not reach safe conditions, what additional altitude was required?
    - The altitudes required had a range of **21 – 1290 ft** (6 – 393 m)
  - 5. How much earlier would ejection initiation be required to have that additional altitude available?
    - Based on the vertical velocity at the time of ejection (assuming it was constant in the few seconds before ejection)

- With an earlier initiation timing for each unsafe ejection with a modern seat, **how many additional ejections would have passed the safe condition requirement** and not have been OOE?

OOE Analysis: Results

- OOE Reduction
  - 0.25 s – 26
  - 0.50 s – 58
  - 0.75 s – 91
  - 1.00 s – 110
  - 1.50 s – 140
  - 2.00 s – 147
- Maximum 149 fewer OOE
  - Increases the predicted rate of safe conditions up to **98.8%** for live ejection conditions
- Remaining 24 cases have no sink rate
  - Earlier ejection would not have any effect



Aircraft Integration: Human vs Escape System

Improving the Survivability of OOE Ejections

- This results highlights an improvement to escape performance with significant potential
  - This could be achieved with either:
    - Novel technologies
    - Better training
    - Enhanced integration
- Novel technologies could include:
  - Faster parachute timings through sequencing
    - Would likely result in not meeting injury metrics
  - Pintle motor (more thrust in an optimal direction controlled by feedback loop)
    - High cost and reduced reliability
- Previous section showed the dramatic reduction in OOE by 1-2 sec earlier ejection initiation
  - Would better training (one of the HSI Domains shown on Slide 5) be a better way to achieve this?
  - Expect to see a conflict with aircrew need to delay ejection as long as possible to both try and recover the aircraft and to ensure no casualties on the ground, even with additional training

Aircraft level system integration

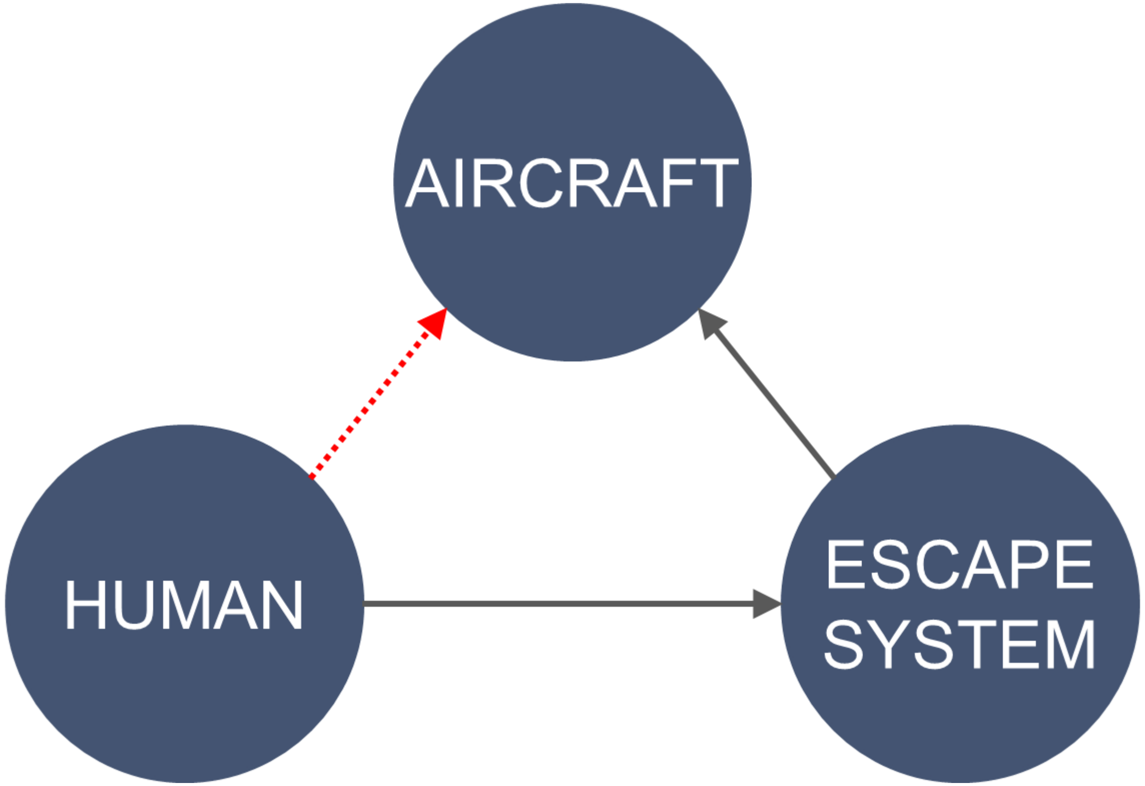
- Enhanced integration of the human with the aircraft and escape system (core to HSI mission) could allow the aircrew to delay as long as possible, but not eject outside the envelope
  - Could an auditory and/or visual warning help the aircrew know when the last moment to eject is?
    - It would require information to be transmitted from the aircraft to the human
    - Also done prior to initiation of the escape system, which is independent and dormant

- A good example of aircrew being assisted by this enhanced level of integration at and beyond the boundary of human reactions is the auto-eject on the F-35B (STOVL)
  - In the event of a lift-fan failure, the seat will automatically be commanded to eject as it will be OOE before a human has had time to react to the situation
  - What has been learned from this experience?
    - Martin-Baker can model and provide the necessary information on escape system performance to the aircraft manufacturer
    - By taking this into account the human can be better integrated with the aircraft from the start

- It is then clear that the human cannot be directly integrated with the aircraft in isolation
  - Because a key interface between the human and the aircraft is through the Escape System

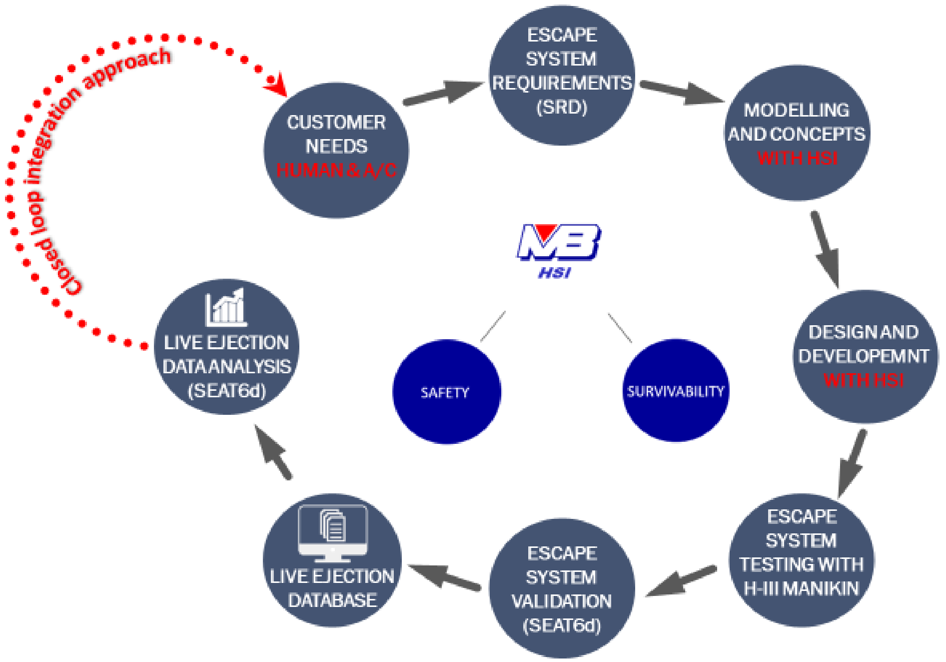
The missing link of integration

- Therefore, the human has to be integrated with the escape system, and that with aircraft
  - Human → Escape System Integration
    - **Historically**, MBA has been asked to **accommodate** a human, **not** to **integrate** them
    - Our increased **focus on HSI** aims to achieve **true integration of the human**, as a system element, not just an operator
  - Escape System → Aircraft Integration
    - **Early engagement** gives the best results
    - Also need **specialised knowledge** such as AEA, LSS, maintenance, etc. to be represented
    - The **human needs** must be **included** when setting requirements for the escape system
- Note that other forms of integration exists and must be considered in other HSI Domains
- The identified missing link means there is an opportunity to close a gap in the integration process
  - How can this be achieved?



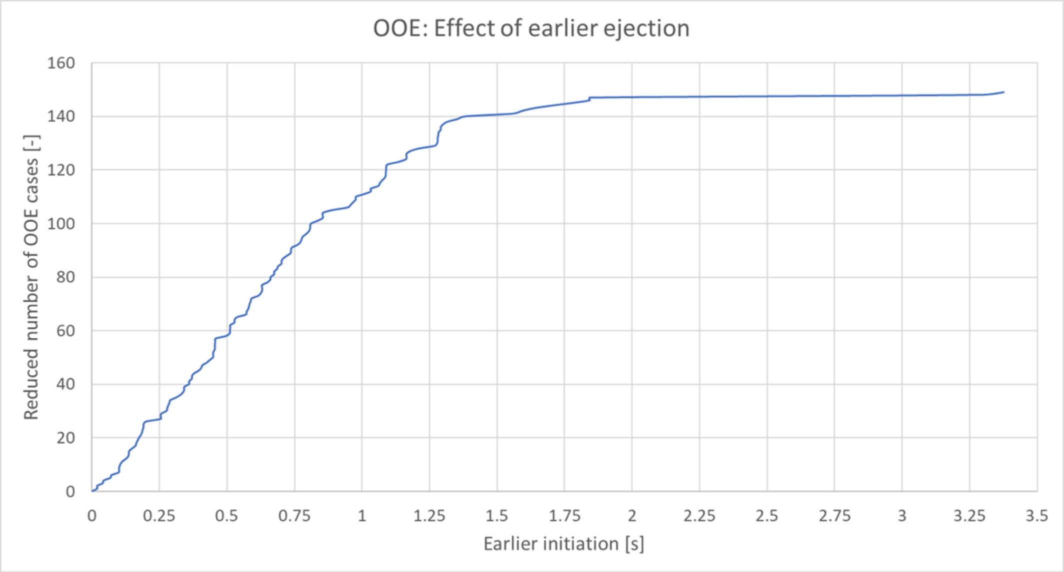
Closing the loop on Integration

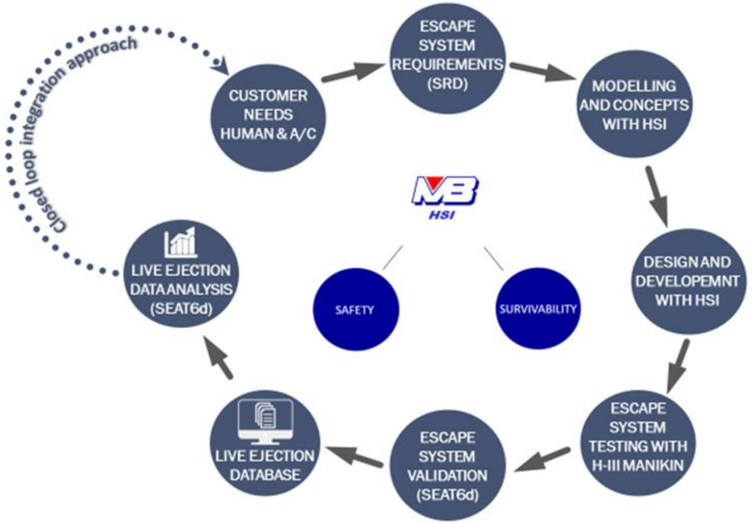
- Traditional methodology
  - Customer needs arrive at the start of a programme
  - Tend to focus on the aircraft system without the human as a system element
  - Concepts and development do not utilise full HSI methodology
  - Live data with outcomes not fed back into the needs for the next programme
- By changing the above points, the integration loop can be closed
  - Similar to the closing of the research loop
    - Also presented at SAFE Europe 2022 by Dr Bilger in *Post-Ejection Reporting: A Questionnaire Approach*
  - Allows for an iterative approach between programmes for the benefit of all stakeholders
    - Need a collaborative approach in the early stages
    - Spiral upgradeability means such enhancements could also be introduced on a current programme



Summary

- HSI enhances performance where the human is key – such as a crewed 6th gen fighter
- Different tools work for different domains
  - Seat6d great for Escape System Survivability
- Analysis of OOE shows 1-2 seconds earlier is key for a seat with modern performance
  - Based on the historical cases
- Integrator and manufacturer of escape system need to collaborate from the start
- Two key levels of integration for Survivability:
  - Human → Escape System
  - Escape System → Aircraft
- Small modifications to adapt the V-model to an O-model, allowing the closure of the integration loop





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Lives saved to date

THANK YOU

Any questions?