EJECTION SEAT ANALYSIS

ED17B011

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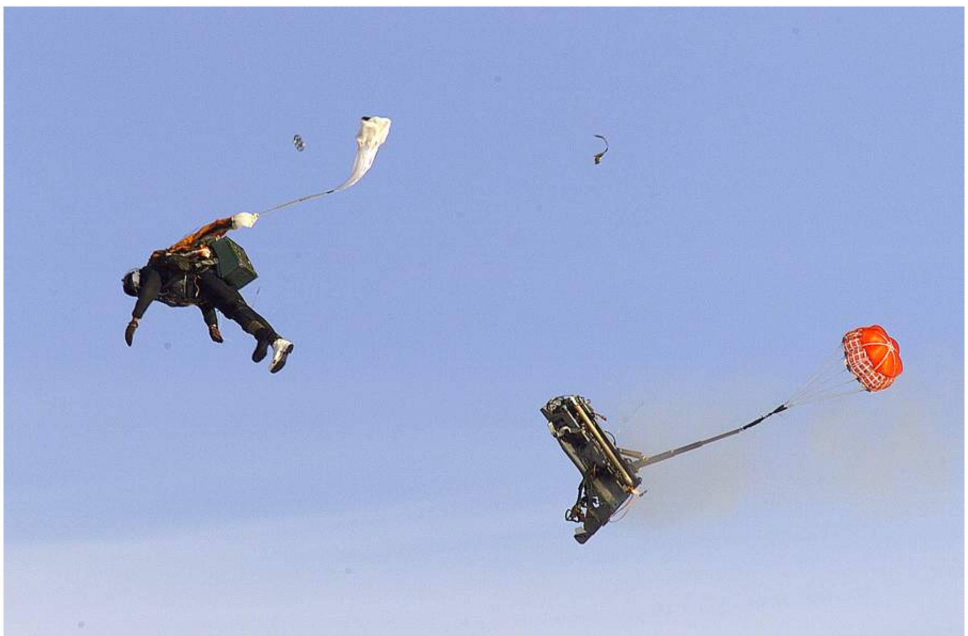
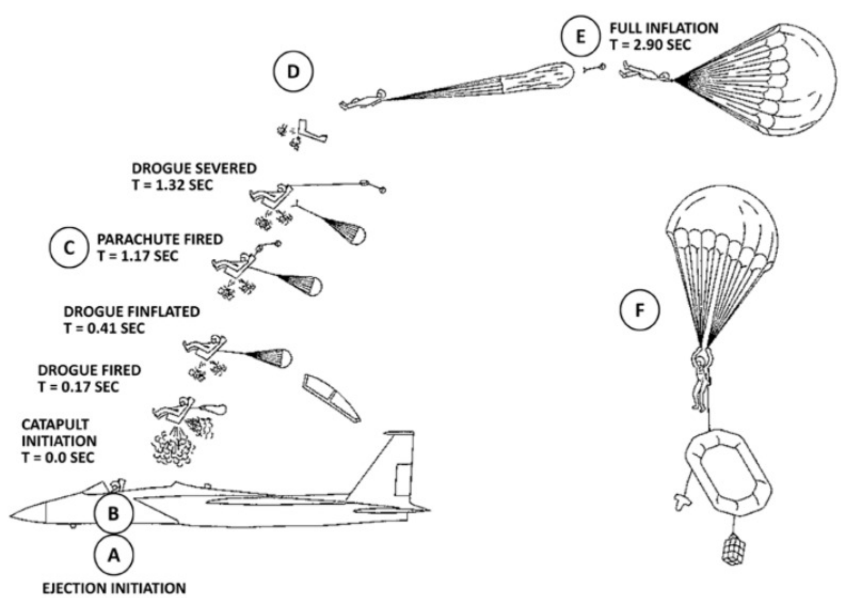


1 Abstract

Ejection seat mechanisms are observed and studied in the light of various use cases. Test metrics are defined to evaluate the seat's performance in various scenarios. Usability tests are devised to assess various cognitive and physical/bio mechanical factors involved in ejection. They are then related to the metrics they affect. A methodology to evaluate the seat metrics based on the tests is provided.

2 Introduction

Ejection seats help safe manual bailout of the pilot in emergency situations when the aircraft goes out of control. With a steady rise in aircraft performance and speed, there is an equal need to develop ejection seats that can facilitate the removal of the pilot despite the strong G-forces as high as 17 - 22 G and wind.



The general steps during an egress are shown in the figure. The first step is the blasting of the aircraft canopy, synchronised with the firing of the rocket catapults/pyrotechnics used to launch the seat into ejection. The second step is the deployment of the drogue parachute to stabilise the seat from tumbling due to wind blast. The third step is the firing of the tilt-based vernier rocket that will orient the rocket upwards and still maintain stability. The fourth step is the deployment of the main parachute. The fifth step is the release of the drogue parachute and the sixth is the firing of the seat separator rockets and the seat separation. The seventh step is parachute deployment or canopy spread.

Ejection is a violent and dynamic procedure, which happens extremely quickly once the ejection handles are pulled. If the pilot is not in proper ejection position or does not follow proper procedures, serious injuries or death can occur.

3 Analysis

To evaluate an ejection seat, the scenarios in which it will be used need to be understood and studied. Use cases help identify the ideal behaviour of a system and make it easier to identify the factors that might adversely affect the process during that specific procedure.

3.1 Use cases

3.1.1 As a normal seat

It is important to note that this seat will also be used as a regular seat by the pilot during normal flight.

3.1.2 To eject or not to eject

It has been observed that a lot of ejection that are unsuccessful are due to late ejection of the pilot as the plane is dropping fast under gravity. This is because the ejection seat has to overcome both the downward velocity and acceleration of the plane. Psychological state of the pilots under different conditions like war, training, etc should be studied and understood to analyse the design better. The delay in decision making time can cost lives.

3.1.3 Zero-zero ejection

Zero-zero ejection extracts the pilot upward from a grounded plane, i.e., zero velocity and zero altitude and lands him away from the plane. It is very important to consider this use case as it helps save lives in late ejections or when the plane is stuck or in ground accidents.

3.1.4 Ejecting while accelerating/decelerating

The G forces acting on the pilot during acceleration are the highest. Here there is an impossible trade-off between comfort and safety and safety needs to be chosen at all times. The seat should also sense the speed and acceleration/deceleration of the plane and decide, after sensing the orientation, the trajectory of ejection, and control the propellers accordingly.

3.1.5 Ejection at all orientations

When the plane is performing the manoeuvres Pitch, roll and yaw, ejection should still be possible in the case of a crash. The extreme case is when the plane is upside down, where the seat should propel down and out and then propel up. The orientation of the plane and the ejection mechanism's response to the orientation needs to be studied

3.1.6 Canopy opening-ejection coordination

The mechanism that opens the canopy right before the ejection blast is very important as it needs a lot of accuracy. A little early could change ejection dynamics and a little late could kill the pilot. The coordination mechanism will need to be studied and its accuracy will be evaluated.

3.1.7 Ejection mechanism

Whether the seat will be ejected using a single propeller or four at each corner, and how much fuel is used up to accelerate the seat depending on the acceleration and speed of the aircraft are important calculations that will determine the trajectory of the pilot. This will also dictate the G-forces on the pilot. So, testing this mechanism's calibration for speed and acceleration is important. It is also important that the pilot is attached to the seat firmly and so the attaching belts need to be tested for sturdiness. The biomechanics are also analysed as this is when maximum forces act on the pilot. The seat needs to provide sufficient support to the neck and spine which have to be in proper posture.

3.1.8 Detachment of seat

Once the parachute is opened, the seat dismantles, detaches itself from the pilot and falls away. It should be ensured that the seat falls faster than the pilot and the parachute. The belts that held the pilot fast to the seat must be easily unfasten-able now.

3.1.9 Ejection enevelopes

It is paramount that the ejection seat escape the **fireball** produced by the aircraft blowing up. The performance of the seat outside the safe ejection envelope needs to be studied.

4 Metrics to be tested for

4.1 Pyrotechnics and Flight dynamics

Assuming the seat is catapulted using pyrotechnics, these are the various metrics that need to be borne in mind while designing usability tests

4.1.1 Stability

This can be described as the rocket's ability to stay on course despite gusts of wind etc. This also includes the tendency to tumble.

4.1.2 Seat manoeuvrability

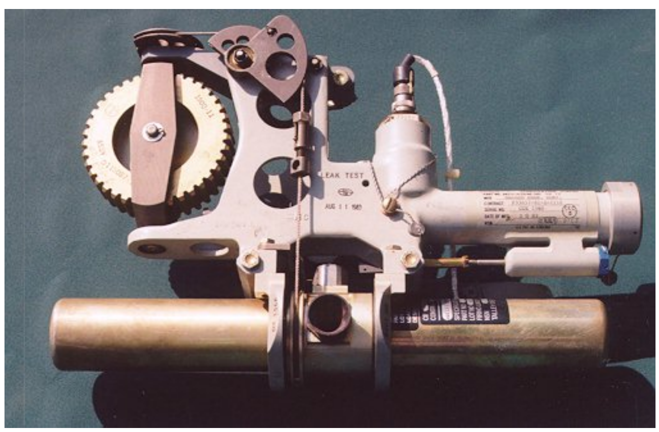
The maximum possible acceleration and the sensing, control and display of the acceleration, velocity and altitude is also a very crucial factor especially in steering away from fireballs and adverse winds. There are a lot of 'implied' metrics here; such as range, wind turbulence stability etc.

4.1.3 Maximum Acceleration

This is the acceleration that can be obtained due to the thrusters. This also depends on the weight of the pilot, so we calculate all the values taking the average weight of a pilot to be around 68 kg. This will also depend on the rocket's fuel capacity or ballistic gas pressure etc.

4.1.4 Vernier sensing and uprighting

Even when the ejection has been done upside down, the rocket's ability to propel the seat upward after clearing the fireball range of the aircraft depending on the altitude is also an important parameter. Shown in the figure is a STAPAC rocket that takes care of the uprighting.



4.1.5 Controls, sensing and autonomity

The ability of the seat to maneuver itself depending on the altitude and environmental conditions it senses and follow optimal trajectory needs to be evaluated with mannequins of various weights

4.2 Time

Time is one of the most crucial aspects in ejection. Especially when altitudes are high, pilots often tend to under-estimate sink rates. Almost 85% of the casuality cases involve the pilot pulling the trigger a little late or not sticking to the decision to eject and trying to save the plane.

4.2.1 Decision making time

The cognitive aspects need to be studied. This is a very important metric. It depends on various factors such as the personality of the pilot, his ability to recognise that the situation is beyond repair, fight, flight or freeze tendencies of the human nature etc. This is can be a separate study, to simulate the pilot's environment and train them to make the best decisions.

4.2.2 Reach time

The time taken from when the decision has been made to when the trigger/switch is pulled. This depends on the pilot's anthropometry as well. the trigger can not be placed too near, lest it be pulled accidentally. It cannot be placed too far as that may cost the pilots their lives.

4.2.3 System response delay

Inherent delay in the controls and mechanical responses of the system.

4.2.4 Canopy open time

Time taken for the canopy/chute to open.

4.2.5 Parachute open time

Time taken for the parachute's canopy to open completely after being triggered.

4.3 Ejection envelope

It has been found that though pilots have sustained injuries due to impact landing, the chances of them being killed by the fireball of the crashed aircraft are much higher. So this makes us consider the range of the propellants, the ejection velocity and acceleration. here, there is a trade-off between acceleration and range. The more acceleration one has, the farther away from the aircraft one can get. But, the tolerable G-forces will dictate an upper limit to this acceleration.

4.3.1 Safe ejection envelope

The envelope described by the possible positions of the aircraft in the time within which ejection needs to be carried out for safe ejection at a certain velocity and altitude shall be described as the safe ejection envelope. The larger the envelope, the better, as it gives the pilot more leeway to recover/ eject at a later stage.

4.3.2 Maximum horizontal range

This will be the Range measured in a zero-zero ejection, as in all other cases, the range will be greater than this value if the controls are appropriately designed. This range is a much needed metric as it needs to be compared against the size of the fireball that would be caused if the aircraft exploded on a full tank. Ideally, the range should be safety factor times the radius of the fireball.

4.4 Seat

The sturdiness and structure of the seat helps prevent differential acceleration of various parts of the body of the pilot thus keeping him safe during the rocket catapults.

4.4.1 Structure and Geometry

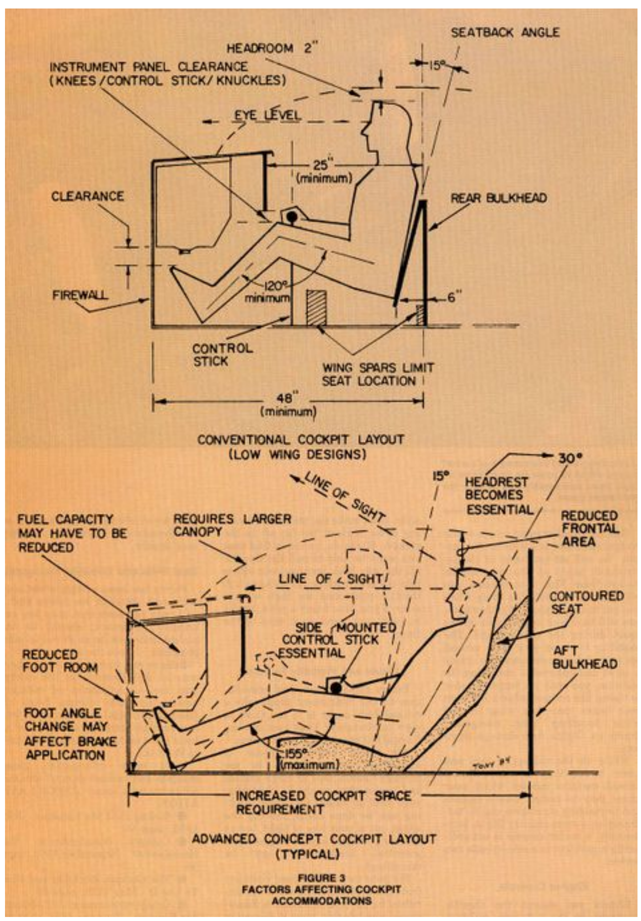


FIGURE 3
FACTORS AFFECTING COCKPIT
ACCOMMODATIONS

This describes the posture of the pilot while flight and ejection, and is very important to avoid breaking of bones and provide structural support. The seat should maintain ranges of knee, hip/back, neck/spine support and joint angles that are optimised for the trajectories of ejection.

4.4.2 Mass and Moment of Inertia

The moment of inertia and mass are important physical parameters that determine acceleration angular velocity etc.

4.4.3 Belt and face curtain tensile strength

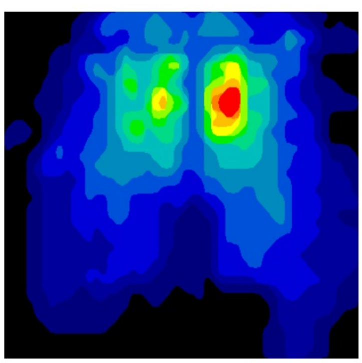
The belt holds the pilot to the seat and the face curtain shields the pilot from debris. The sturdiness of these parts determine the pilot's safety.

4.4.4 Acceleration variance

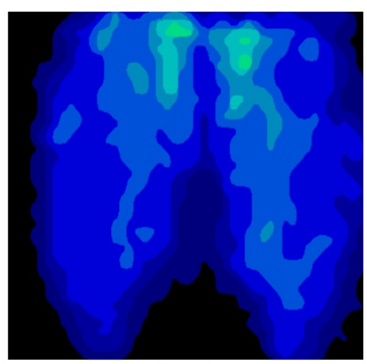
At times, severe injury occurs due to differential acceleration of various parts of the seat due to different masses/ moments of inertia etc. This variation in acceleration in extreme cases needs to be measured and minimised.

4.4.5 Material properties

Young's modulus and damping factor of the material used in building the seat plays a pivotal role in transmitting or damping out the external impulses and vibrations. If the seat is made uniformly soft, the spine may not have adequate support. The thickness and stiffness of the seat needs to be varied at different parts of the seat, depending on the pressure profiles observed.



Cell E (ACES II)



Cell X (APECS)

5 Usability testing

According to the MIL-STD-810 the following tests have to be performed to ensure that the standards are being followed. Apart from that a test similar to the driving test (8) has been devised to evaluate the said metrics. Each test has a basis and a methodology.

5.1 Vibration test

Basis: It is essential that any vibration testing protocol accurately reproduces the diversity of forces encountered by an object over the course of its operational life. Random vibration testing to failure can identify weaknesses and other design issues.
Methodology: The DUT is subjected to sinusoidal and random vibrations and noise of specified frequency and spectra as dictated by the standards. To find the dynamic properties of a structure, the response to a vibrational force is of interest rather than the actual vibration level. Further test details can be found in reference [2].
Inference: From this we can determine metrics such as mechanical impedance of the seat, damping coefficient, failure modes etc. We can also determine the structural dynamics and sturdiness of the seat.

5.2 Thermal Shock Testing

Basis: Ejection seats undergo air-to-air thermal shock testing where the test product moves from one extreme atmospheric temperature to another when the egress is initiated.
Methodology: For a higher rate of thermal transfer of greater thermal energy, we can utilize a liquid-to-liquid system. The process works essentially the same as the air-to-air thermal shock by using a basket to mechanically transfer the test article from one vat to another. Testing requires either simple atmospheric or highly pressurized sub-freezing temperature shock.

Inference: From this we can determine metrics such as material properties of the seat like thermal conductivity etc.

5.3 Explosive Atmosphere Testing:

Basis: Explosive atmosphere testing determines whether the ejection seat will be able to operate properly in a fuel contaminated, highly volatile environment without creating ignition and causing an explosion. This test is especially necessary given the pyrotechnic catapults used.
Methodology: For a full service explosive atmosphere test facility, we need to provide fuel and vapor mixtures using either hydrocarbon n-hexane, propane, hydrogen gas and/or jet aircraft fuel. For aircraft and space applications, chambers that simulate altitudes to 100,000 ft (30,480m) and can provide temperatures up to +300F (+150C) are needed.
Inference: From this we can infer the safety of the pyrotechnics used.

5.4 Altitude testing:

Basis: Altitude testing examines assemblies and parts that operate in high altitude, such as the cockpit of an aircraft. Testing also subjects components — seals, safety equipment, ejection mechanisms and optical gear — to rapid and catastrophic decompression.
Methodology: Temperature: Temperature lapse rates average 3.5F for every 1,000 feet of height. Components designed for use in aircraft and aerospace equipment must be able to withstand not only extreme cold but also the rapid temperature changes experienced during takeoff and landing.

Humidity: With changes in temperature come changes in humidity. Sensitive components must be able to withstand these conditions, too. The tight tolerances required of commercial and military equipment necessitate humidity testing to ensure they will deliver the performance required of them at all times.

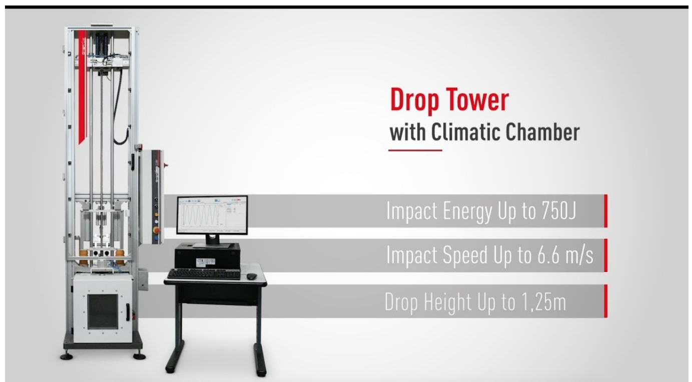
Pressure: MIL-STD-810, RTCA DO-160 and other standards govern acceptable behavior of internal and exposed aviation equipment when subject to rapid decompression. Altitude testing helps you maintain compliance and deliver a reliable product for use in any application
Inference: From this test we can gauge the durability of the ejection seat to decompression, thus evaluating the metrics; material properties and structural strength.

5.5 Shock test:

Basis: Shock testing of the seat to what degree it can physically and functionally withstand relatively infrequent, short time, moderately high-level force impulses or temperature changes that would be encountered in handling, transportation, and service environments
Methodology:

- Pyrotechnics to simulate pyro-shock — Pyro-shocks are often encountered in spacecraft flight when rocket booster stages are separating and in military applications when weapons are being fired or ordinances are being detonated.

- Drop Testing — this occurs up to 80ft (24m) for testing the resilience of items against mishaps that could happen during transportation, handling, and expected use.



- Drop towers to induce mechanical shock — Our drop towers are able to deliver peak acceleration in excess of 20,000g (196,000 m/s2).

- Air gun generated hydroshock — In this type of test, an air gun fires a blast of air into a volume of water to generate shock waves within that volume of water.

- Free-fall and variable force test techniques — These techniques produce shocks up to 15,000g (147,000 m/s2).

- Simulated catapult launch/arrested landing per MIL-STD-331.

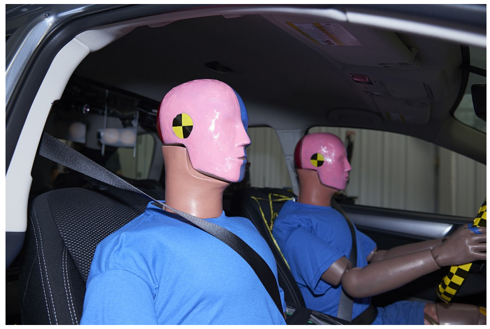
Inference: From this we can determine the material properties such as yield strength and structural sturdiness.

5.6 Pilot simulator test

Basis:

This test is designed keeping in mind the gap between the subjective evaluation of the pilots and the objective values of the parameters/metrics.

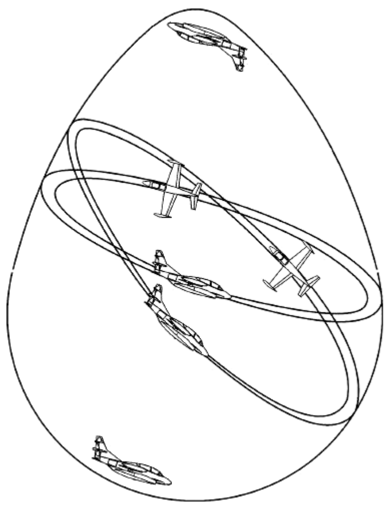
Methodology: The proposed test is to use 2 separate environments for the testing: **the ejection end** and **the pilot simulator end**. At the ejection end, the ejection seat will be controlled by two kinds of cords: The aircraft acceleration simulator cords and the bungee cords to hold the seat from crashing to the ground. The ejection seat will also have a test dummy with temperature



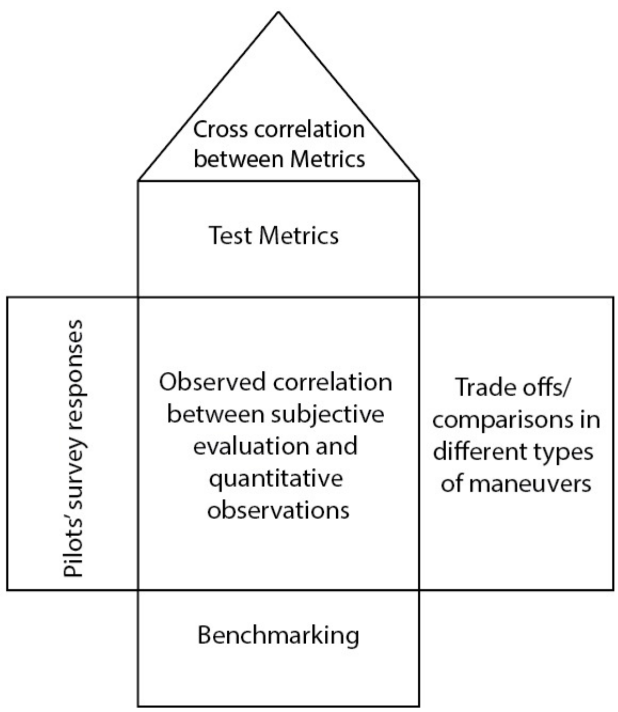
sensors and load sensors to gauge neck, lumbar and other such loads.
These loads will be simulated until a permissible limit, crossing which the test will be deemed to be a failure, at the pilots end using smart seats as they fly a simulated plane, in an indoor skydiving environment that replicates the conditions at egress.

The separation of the pilot and the flight environment is necessary to avoid any accidental injury to the test subjects. The test will include performing of

various military maneuvers like ribbon scissors, and out of plane flying on an egg-like surface to test various turns at all kinds of curvatures.



Each test subject will be given various maneuvers to perform, followed by a questionnaire that collects the subjective opinions of the pilot regarding the seat and various scenarios (use cases). This test can also analyse the decision making part that involves cognitive effort by measuring the pilots EEG. This



will then be correlated with the data obtained from the sensors at the ejection end test rig. This analysis can be done using the House of quality method as shown.

Inference: This test is similar to the driving test 8 and will cover all possible use cases and metrics and help bridging the gap between the subjective experiences of the user, i.e., the pilot and the measurable test metrics obtained from the test rig.

This will also help us study the decision making that goes into an ejection decision although it might not be completely accurate as the stakes are not as high. To overcome this the pilots need to be subjected to cognitive stress prior to taking the test.

6 Future direction

From the data obtained we can make customised improvements to the product like:

- Smart alert systems to help the pilot make the egress decision with better chances of survival at an optimal time.
- Smart pyrotechnics that sense and avoid fireballs and gusts of wind etc.
- Parachute straightening mechanism to unfurl the double canopies formed due to unfavourable conditions.

7 Discussion (learning summarised)

We have analysed the ejection mechanism and understood it completely. We have broken it down into different possible use cases and defined metrics that will help evaluate all these scenarios. We have also come up with a universal test and methodology to observe and analyse all possible scenarios. We also learnt how to look at the obtained information in an organised fashion so as to identify the setbacks easily. A future direction was also indicated in which further product development might take place.

8 Conclusion

The testing method provided in the report has to be examined even more carefully and minor inherent biases/drawbacks of the testing method have to be identified and nullified with suitable techniques. The situations being very volatile, great care has to be taken to design and calibrate each part to perfection.

9 References

[1] https://www.bksv.com/media/doc/br0227.pdf
[2] https://apps.dtic.mil/dtic/tr/fulltext/u2/a112533.pdf
[3]http://www.ejectionsite.com/
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