# LAMIA Flight 2933: Who Lived, Who Died, and Why

**Anthony T. Brickhouse** (MO5069), Embry-Riddle Aeronautical University, United States

**Diego M. Garcia (**ST7465), Embry-Riddle Aeronautical University, United States

**Julian E. Echeverri**, Aviation Accident Investigation Group. Colombian Civil Aviation Authority, Colombia

*Brickhouse: Anthony T. Brickhouse is an associate professor at the Daytona Beach campus of Embry-Riddle Aeronautical University. During the span of his career, he has investigated numerous aircraft accidents and safety events. Brickhouse holds a Bachelor of Science degree in Aerospace Engineering (spacecraft design) with minors in mathematics/aviation safety and a Master of Science degree in Aeronautical Science with a specialization in Aviation/Aerospace Safety Systems. Professor Brickhouse is a full member of the International Society of Air Safety Investigators (ISASI). He is also the International Coordinator of Student Outreach and Mentoring for ISASI.*

*Garcia: Originally from Colombia, Dr. Garcia is an accident investigator with a medical degree in aerospace medicine and a master's degree in human factors. As a safety specialist, he has worked for over a decade in both military and civilian aerospace operations applying human performance and systems-thinking precepts. Also a published author and researcher, he has contributed to safety as lecturer and professor in Colombia and the USA.*

*Echeverri: Julian Echeverri is an aerospace engineer and an accident investigator with 11 years of experience within the Colombian Accident Investigation Authority. Trained internationally, he has collaborated in numerous Annex 13 accident investigations. He is a LARSASI member and Colombia's focal point member of ICAO's LAR region. His leadership, expertise, and knowledge in events such as LMI2933, have led him to collaborate in the development of manuals, policies, and guides for investigators.*

## Introduction

An Avro 146-RJ85, performing a charter flight LAMIA LMI2933 for the Brazilian Chapecoense football team, was destroyed after impacting a wooded hillside south of Rionegro/Medellín Airport, Colombia. The official accident investigation board included over 20 experts from 5 states. At the end of the investigative process, the board determined fuel exhaustion as the cause of the crash. Out of 77 occupants on board, only six survived the accident. Five occupants suffered serious injuries and one occupant sustained minor injuries. Crashworthiness and survivability analysis were performed to assess the conditions that allowed these occupants to survive the crash.

## Methodology

It is taught in academic circles around the world that for occupants to survive an accident, specific stipulations must be met. Occupants must have occupiable living volume during the dynamic portion of the crash. Decelerative (G-forces) must be within human tolerances. Finally, occupants must survive all post-crash factors until rescue and medical treatment occur. Air safety investigators use the CREEP methodology (Container, Restraint, Environment, Energy absorption, and Post-crash factors) to assess the different factors that influence survivability in a crash. Actual flight data, crash scene analysis, medical and forensic information, and personnel interviews from this accident were gathered to determine acceleration loads, magnitude and duration, aircraft structural collapse, and energy absorption. Also injury causation, search and rescue, and healthcare services for the aircraft occupants were also explored. All five CREEP factors were depicted and weighted for each one of the six survivors in order to evaluate what specific conditions contributed to their survivability.

## Results

CREEP elements played different roles for each one of the surviving occupants of the accident aircraft. Energy absorption and restraints were decisive for all six survivors. The container was a protective factor for just three of them, while environmental factors during the crash dynamics were also important as a protective element. In contrast, post-crash factors were detrimental for all of the six survivors

## Discussion

Occupant survival analyses derived from aviation accidents are crucial for crashworthiness design, but also for education, research, and safety enhancements of current aerospace systems. A comprehensive survival analysis, especially when occurrence circumstances diminish the odds of survival for occupants like in this case becomes paramount. Research can contribute to the enhancement of aircraft design and restraint systems, the improvement emergency services, the advance of accident investigation techniques, and in general an augmented awareness and understanding of safety promotion and accident/injury prevention for the general public, operators and regulators.

## Background

The Aerospace industry nowadays is labeled as an ultra-safe industry given the safety performance indicators assessed by the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA). According to recent research, where accident rates were in between 12.2 fatalities per billion passengers in 2017 for the former, and 1.35 per billion in 2018 for the latter. (1,2) Even though these indicators are near their historical best, high-profile accidents involving commercial aviation operators bring high impact consequences on the general public in terms of trust and willingness to use airline transportation services. Recent studies described a survival percentage of 81% in all aircraft occupants of commercial passenger aircraft accidents and in 90% of the accidents there was at least 1 survivor. (3)

According to different aspects and elements unique for each one of the occurrences, the outcomes in terms of survivability of an accident are a dichotomously categorized as survivable or non-survivable (4). This is not unusual that in spite of the theoretically exceeded human tolerance capabilities in certain crash events, still one or more surviving occupants are accounted in the aftermath of the accident. This is precisely the case for the supervivient occupants of the LAMIA Flight 2933 that crashed near Medellin, Colombia in November of 2016.

Accordingly with the Colombian Aviation Accident Investigation Authority (GRIAA), the accident aircraft, an AVRO 146-RJ85, registered with the tail number CP 2933, was conducting a chartered flight from Viru-Viru international airport in Santa Cruz de la Sierra - Bolivia (ICAO: SLVR) to José María Córdoba international airport, Rionegro - Colombia (ICAO: SKRG). The aircraft was carrying the Brazilian football team Chapecoense and also, some journalist and administrative directives from the team. During a holding pattern waiting to be authorized to intercept the localizer for the approach to runway 01 of José María Córdova International Airport, the aircraft suffered a sequential flame-out of its 4 engines and impacted the southern slope of a mountainous terrain located 10 nm south from the threshold of runway 01 of SKRG at 02:59 zulu time, in night time and rainy weather conditions. (5)


Figure 1. General appearance of the Avro 146-RJ85.
Source: *GRIAA. Final Report. Accident. COL-16-37-GIA Fuel Exhaustion AVRO 146-RJ85, Reg. CP 2933 29 November 2016 La Unión, Antioquia – Colombia*.

The investigation process identified the following causal factors:

- Inappropriate planning and execution of the flight, by the Operator, in regards to the amount of fuel required for the safe completion of the intended flight.

- Sequential flame-out of the four (4) engines as a consequence of the exhaustion of fuel on board.

- Inadequate decision making on the part of the aircraft operator's company management, in terms of the implementation of operational safety in its processes.

- Loss of situational awareness and wrongful decision making by the flight crew, because of the fixation of continuing the intended flight with an extremely limited amount of fuel.

There was no post-impact fire and the aircraft was destroyed as a result of the crash dynamics. Out of a total of seventy-seven (77) occupants, seventy-one (71) occupants perished and six (6) occupants survived with serious and/or minor injuries.(5) Despite the high energy impact, the almost complete destruction of the airframe, the rough environmental conditions after the crash and the limited first responders assistance secondary to the geographic conditions of the accident site and the accessibility from there to definite health care services, an initial number of 8 survivors were found among the wreckage in the accident site. Unfortunately, one of these initial survivors was lost in the crash site itself before the evacuation, and another died from his injuries in the regional hospital shortly after his arrival.

Crashworthiness and survival aspects of occupants for accident investigation processes usually follow a widespread methodology commonly known as CREEP (6). The resulting acronym is explained in Table 1.

After taking into account all of these different factors and determining how injury causation is related to the extent of the affectation to personnel derived from all these dynamic and complex interactions, accident investigators can point to one or various of these elements as the potential source of injuries to occupants and the different levels of injury severity generated by their interaction.

In this way, after an accident investigation, fatalities, severe and minor injuries are explained in terms of CREEP elements for the specific occurrence and the specific conditions that each accident presented to occupants. This depends on their position in the airframe, the energy amount and dynamics of the crash, the correct and effective use of different types of restraining systems, their opportunity to egress the scene and the support received after the event among other factors. Unfortunately, when the investigation process determines that all these elements were against occupant survival, and still, we are able to account for one or more supervivient occupants, other analysis and factorial assessment should be considered. This is the case with LAMIA flight 2933. The objective of the present study is to analyze the different elements of CREEP methodology for the six survivors of LAMIA 2933 flight.

Table 1. CREEP survivability methodology

| Acronym | Factor | Explanation |
|---|---|---|
| **C** | **C**ontainer: | The available living space for occupants resulting during and after the accident dynamics. |
| **R** | **R**estraint: | Seats, belts and other restraint systems protecting occupants from being injured against other structures and elements, and preventing them to be projected inside and out of their living space. |
| **E** | **E**nergy | The deceleration forces suffered by occupants during the crash, since occupants are no fixed part of the airframe, energy can be either attenuated or amplified. |
| **E** | **E**nvironment | This refers to all the surrounding factors created by the crash that can injury occupants, like fumes, extreme heat or cold, toxic materials or fast moving objects within their living space. |
| **P** | **P**ost Crash Factors | Referring to all the different situations and elements that can affect occupant survival after the dynamic portion of the accident, post-crash fire and smoke, wreckage evacuation and search & rescue systems are the most relevant elements under this domain. |

<u>Kinematics</u>

For the survival factors analysis specific to the crash of the LAMIA 2933 flight, the authors of this study referred to the official Final Report published by the Colombian Civil Aviation Authority (CAA) and GRIAA, where crucial data are depicted and analyzed. These data included weight and balance, speed, distances, accelerations that were mainly retrieved from the flight data recorder (FDR), cockpit voice recorder (CVR), and operational records and forms. The final report included pictures, diagrams, formulas and calculations for relevant information related to injury causation to occupants. Other publicly available resources such as interviews, expert analysis, documentaries, press releases, and reports were also taken into account.

Following the procedure for CREEP analysis, the authors weighted and modeled all the available information in order to build a general, unified model for the entire airframe and for all occupants. After which a detailed analysis for each one of the surviving occupants was conducted in an individual fashion in terms of energy absorption, container preservation, restraint elements, environmental and post-crash factors. This was done to explain the potential conditions and factors that determined the survivability of 6 out of 77 occupants of the ill-fated flight.

The first approach for the analysis was energy calculations. This was accomplished using the FDR data, crash scene distances, wreckage distribution, and forensic analysis for specific injuries evidenced in both fatal and non-fatal victims of the crash.  This was done to determining the acceleration pulse shape and duration and the onset rate and the magnitude for energy vectors (horizontal and vertical acceleration) using the following equations: (6)

Horizontal G calculation for triangular pulse:

$$G_H = \frac{V_{H1}^2 - V_{H2}^2}{gS_H}$$

Vertical G calculation for triangular pulse:

$$G_v = \frac{V_v^2}{gS_V}$$

Pulse duration:

$$t = \frac{2(V_{v1} - V_{v2})}{gG_v}$$

Where the following:

$G_H$ = Horizontal G loading

$V_{H1}$ = Initial impact velocity

$V_{H2}$ = Secondary impact velocity

g = Acceleration of gravity

$S_H$ = Horizontal deceleration distance

$G_v$ = Vertical G loading

$S_V$ = Vertical deceleration distance

The second approach for the analysis was the CREEP study for the estimation of the resulting living space during and after the dynamic portion of the crash, the restraining systems' characteristics, usability and effectiveness for the surviving occupants and the factorization of environmental and post-crash aspects affecting their possibilities of receiving timely medical assistance, treatment and recovery.

Finally, a resulting model based on an analog scale comparing the estimated contribution of each one of the CREEP elements was consolidated for each one of the surviving occupants.

<u>Results of Kinematics</u>

For energy calculations, estimated weights, distance and speeds were used derived from dispatch records and FDR related elements. This was done in order to replace available terms of the energy magnitude and duration equations. Based on these data and in combination with scene and impact dynamics reconstruction, it was determined that after the initial impact at the top of the hill, a descending energy dissipation trajectory (approximated slope 55°) was generated along a magnetic course of 296 degrees, continuing for around 140 meters (462 ft.) downhill on the northern slope of the ridge. This is where the majority of the aircraft wreckage came to rest almost completely destroyed. The only recognizable sections of the airframe were the tail and empennage section (which was greatly preserved and was found at the top of the hill slightly behind the initial impact site) and the right wing with a small fuselage section attached directly below it (Figure 2). Final distribution and destruction level of the debris also suggested that the main wreckage dissipated the remaining post-impact energy in a snowball-like pattern, with its center in the front portion of the fuselage, which was also the most badly destroyed. This final distribution pattern also explains the final location of most of the deceased passengers, especially those that probably were not using any restraint system at the moment of the initial impact.

The resulting energy calculations for a triangular pulse showed a peak around 70 G in the vertical axis at approximately 0.6 seconds, with an initial rapid deaccelerating force until around 0.8 seconds and then a more steady deceleration until around 4 seconds after the initial impact (Figure 3)

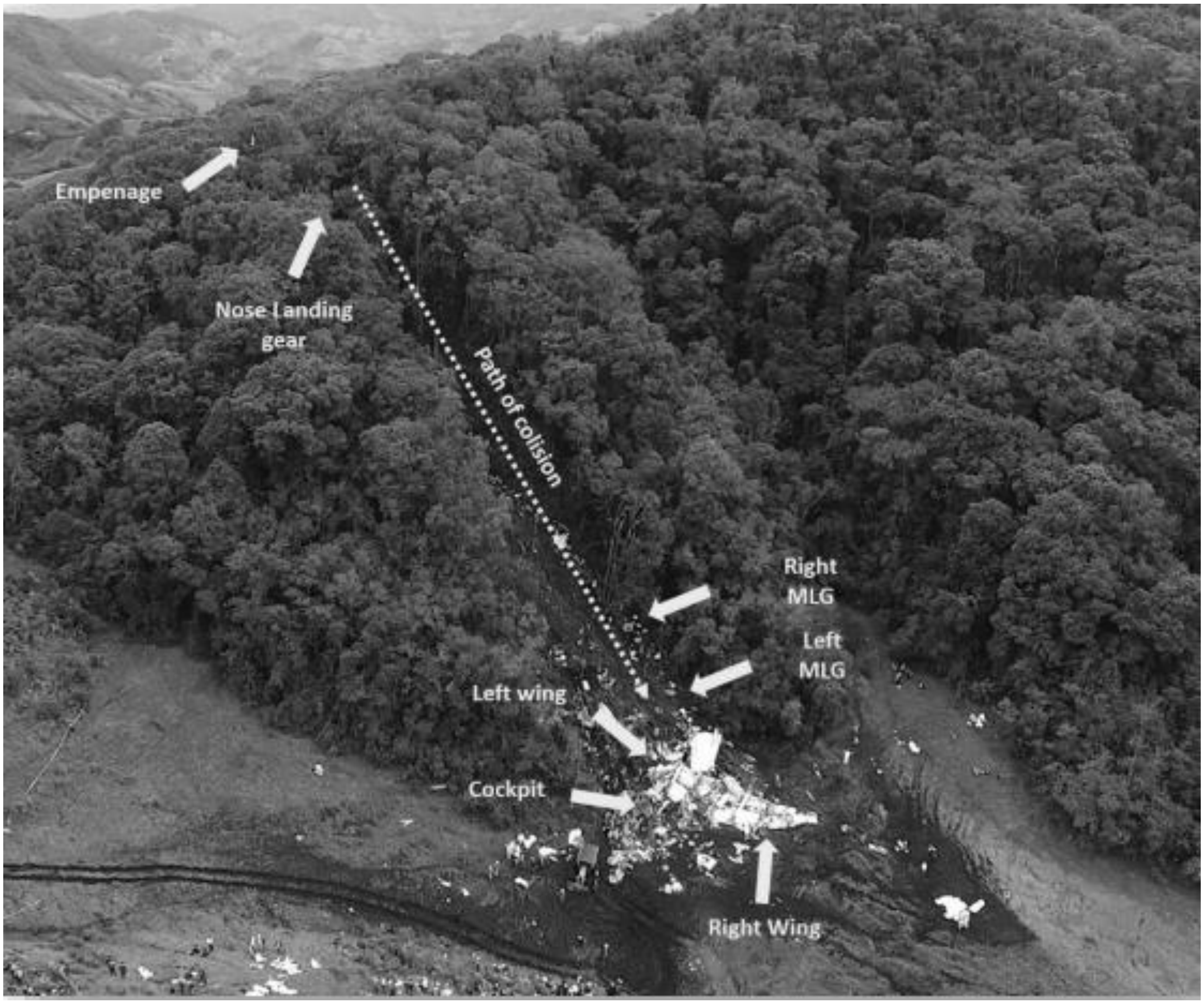



Figure 2. Post-impact path and main wreckage location.
Source: *GRIAA. Final Report. Accident. COL-16-37-GIA Fuel Exhaustion AVRO 146-RJ85, Reg. CP 2933 29 November 2016 La Unión, Antioquia – Colombia*.

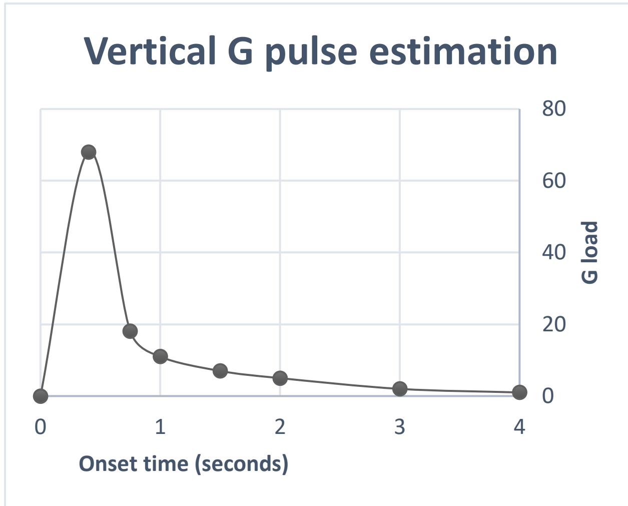
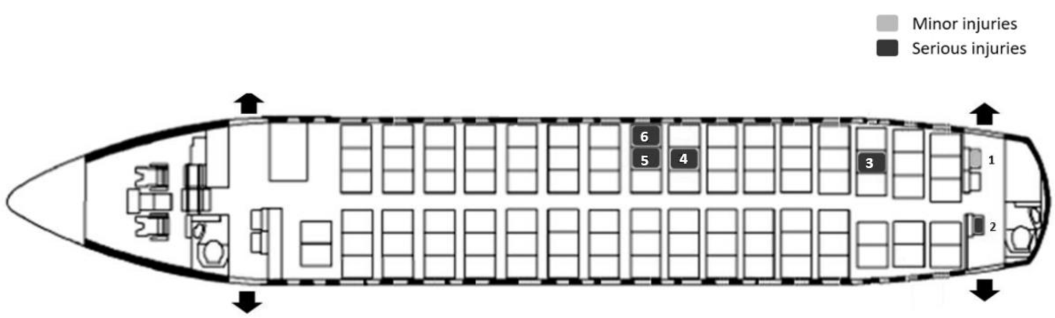



Figure 3. G loads and onset time modeling.

Moving forward into the model, the approximate localization of the six surviving occupants in the aircraft at the moment of the initial impact was assessed in order to determine the container's integrity, the restraint conditions, and environmental aspects such as potential blunt and penetrating trauma produced by fast moving and high energy elements surrounding them during the dynamic portion of the crash. In order to perform this assessment, the approximate map of occupant distribution within the aircraft cabin and type of injuries were taken into account. (Figure 4).




| Person | Aprox. Location (According to survivors statements) | Injuries |
|---|---|---|
| 1 | Right AFT section | Lacerations, Contutions |
| 2 | Left AFT section | Polytrauma |
| 3 | Near to Right Wing | Polytrauma |
| 4 | Near to Right Wing | Polytrauma |
| 5 | Near to Right Wing | Polytrauma |
| 6 | Rear fuselage section | Polytrauma |

Figure 4. Approximate distribution and injuries of surviving occupants.

Adapted from: *GRIAA. Final Report. Accident. COL-16-37-GIA Fuel Exhaustion AVRO 146-RJ85, Reg. CP 2933 29 November 2016 La Unión, Antioquia – Colombia*.

Container

For occupants number 1 and 2, the initial impact was estimated to have occurred right below and behind their seating positions. The energy affectation and dynamics suffered by these two occupants was different than the other four occupants since their seats were rear facing and supported by a structural wall dividing the galley from the rest of the passenger cabin. The container element for these two occupants was appointed to be protective at least for the initial sequence of events, after which they were likely ejected from the airframe and were recovered near the empennage section according to rescuer statements and their own narratives.

Occupant 3 was recovered outside of the main wreckage on higher ground compared to the rest of occupants and main wreckage. For this occupant, there was not enough evidence to determine if the container played a protective role, but probability is low given the injuries received by the close and immediate passengers around him and the condition of the container at the section where he was estimated to be seated.

For occupants 4, 5, and 6, it is highly probable that the container aspect was the most protective element, since evidence from the final wreckage revealed that the upper section of the fuselage, below the attachment to the right wing was the only fuselage section that was almost intact after the crash impact.

Restraint

The restraint element, conjunctly with energy absorption, was believed to be determinant for the type and relatively low severity of the injuries of occupants 1 and 2. As it was previously mentioned, these two occupants were facing rear-wise and wearing 4-point restraint systems. These restraints offered extra protection and prevented further injuries from decelerating forces and during the dynamic part of the accident. For occupant number 3, rescue personnel stated that he was attached by his two-point seat belt to the middle seat of a row a of three, where the occupants to his left and right side were found fatally injured and also attached to their respective seats. These findings indicate that the restraint systems might have played a crucial role for the survival of this particular occupant.

Occupants 4, 5, and 6 were using two-point restraint systems as the rest of the passengers, and according to their own statements, they were using the seat belts at the time of the initial impact. This most definitely contributed to their final survival. For all the seats on the ill-fated aircraft, it was evidenced that the G loads suffered by the airframe and the attaching structures were well beyond the threshold that they can support by design (usually 16 G for passenger seats). (6,7) Most of the recovered bodies from the crash site were found restrained to their respective seats, but a significant number of bodies were recovered outside the main wreckage, along the path of post-impact energy dissipation. This is a good indicator those occupants might not have been wearing their respective restraint systems at the moment of the accident.

## Energy Absorption

The energy absorption and dynamics for the 6 surviving occupants is an element that represent special difficulty for a general modeled assessment. It is highly probable that all of them received high decelerating G forces at the moment of the first impact (around 70 G on the vertical axis). Because of the direction of the higher G peak, the seat design, and according to Eiband curves (8), this energy load might have been survivable for most of the occupants. Unfortunately, energy dissipation and injury prevention in order to allow them to survive the dynamics of the crash were decidedly influenced by the other four elements of the CREEP model.

## Environment

Environmental aspects during the dynamic portion of the crash behaved differently for the six surviving occupants. For occupants 1 and 2, the fact that they were facing towards the rear of the aircraft, the already discussed container and restraint factors and the previously described ejection outside of the main wreckage granted the possibility that other elements moving with very high energy did not represent any injury risk for them. This was also true for occupant number 3. A different scenario was presented to the other three surviving passengers, since they were seated in the middle section of the fuselage, were most of the occupants received fatal blunt injuries from all the heavy and fast-moving elements inside their occupiable space. These elements were seats, luggage, interior cabin structures and also other passenger bodies. For occupants 4, 5 and 6, this element was most likely attenuated by the fact that during the crash dynamics, the fuselage broke into three main sections: one containing the front part of the fuselage, including the flight deck, which was destroyed and mostly disintegrated; then a middle section which included their location and which was fairly preserved around the right wing, precisely where they were seated, and a third section right behind the seats of passengers 4, 5, and 6, which was also completely destroyed.

## Post-Crash Factors

Finally, post-crash factors were determined to be detrimental for all 6 surviving occupants. A total of 8 occupants survived the dynamic portion of the crash. Unfortunately, both perished during the evacuation operation or shortly after arriving to an appropriate medical facility. This was the case because of highly hostile weather featuring persistent rain and cold temperatures, high altitude, long response times of arrival for rescue teams because of the relative remoteness of the crash site. The rescue efforts were complicated by the non-existent access roads to the site and the unavailability of air rescue services. Despite those adverse factors, rescue teams evacuated all survivors on stretchers by foot for at least 1 kilometer (0.6 miles) to a narrow unpaved road, were ambulances and rescue vehicles could pick them up for an approximately hour long drive to the nearest health care facility. Also noteworthy, was that occupant 4 was rescued from the wreckage with serious injuries after approximately four hours after the crash.

The summary model for all CREEP related elements integrated for all 6 surviving occupants is presented in figure 5.

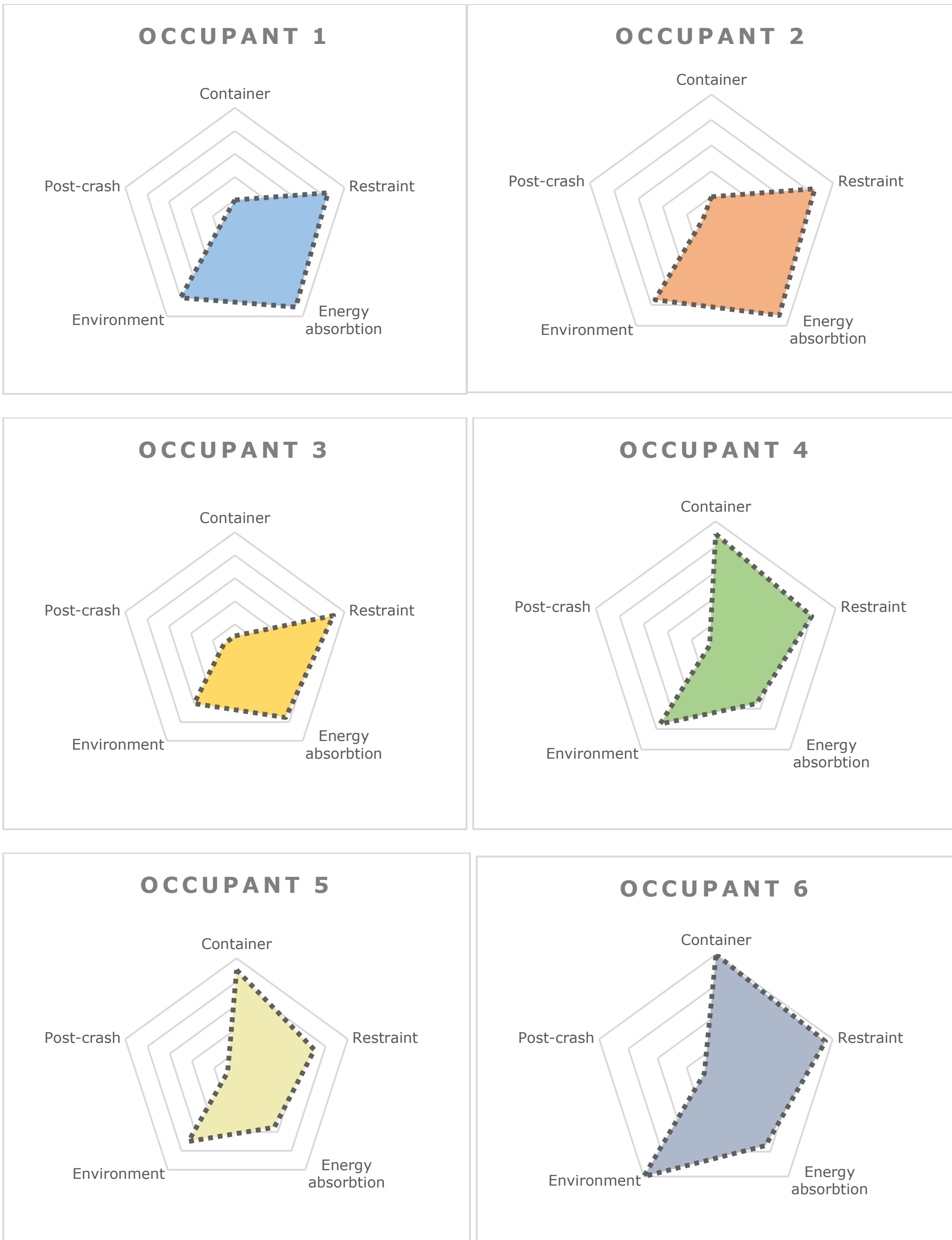



Figure 5. Surface graphs for CREEP elements analysis for each surviving occupant.

## Survivability and Future Safety

"Future Safety" is the aim of any aircraft accident investigation. For survival factors, investigators must ask: If the same accident occurs again, will the outcome for occupant survivability be improved?" If a similar accident to LAMIA Flight 2933 occurred again, would more than six passengers survive? Hopefully the answers to these question will be resounding yes, but it will not happen automatically. Occupant survival analysis derived from aviation accidents are crucial for crashworthiness design, but also for education, research and safety enhancement of current aerospace systems, not to mention search and rescue teams and first responders for events of such magnitude.

Safety performance of the aerospace industry is currently at its best, but when accidents occur, survivability of occupants is still a topic with significant opportunities for improvement. A comprehensive survival analysis, especially when occurrence circumstances diminish the odds of survival for occupants like in this particular case, can contribute to the enhancement of aircraft design and restraint systems, the improvement of emergency services, and the advance of accident investigation techniques. In general, an augmented awareness and understanding of safety promotion and accident/injury prevention for the general public, operators and regulators can also occur.

CREEP analysis presents a comprehensive inventory of factors to take into account for evaluating the different circumstances that contribute to the determination of injury causation and severity of aircraft accident occupants. More research is needed though that possibly involves redesigning or re-evaluating the CREEP model for assessing new and developing factors. Some of the factors that could influence the future of the current CREEP model include newer aircraft seats and pitches, composite materials, and supersonic air transport. A redesigned CREEP model should also account for personnel variability and individual conditions such as age, fitness, physical condition, and gender.

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