LS-208

APPLICATIONS OF PHYSICAL ANALYSIS AND CRASH SURVIVABILITY

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INTRODUCTION

An aircraft accident is always an emotional event that triggers a flurry of activity, particularly if fatalities are involved. Rescuers, damage control crews, search and rescue teams, MEDEVAC teams, and support staff each play a well rehearsed role in activities surrounding the event. Every accident is unique, with its own set of circumstances, surroundings, mysteries and dangers. Initial confusion is always present. But amidst the wreckage, log of events, communication tapes, eye witness accounts, mission briefing, technical manuals, personal interviews and pathology lie important clues that, properly organized and understood, will indicate the cause and the consequences of the accident.

The questions confronting an accident investigation board can vary, but usually involve two issues. The first centers on the cause of the accident. Explaining the cause is fundamental to future prevention of similar accidents. The task of making 'sense' from 'nonsense' can be awesome. An investigating team is usually confronted with a confused abundance of physical and human evidence, and an organized approach to information collection and analysis is needed to succeed.

The second issue centers on the consequence, specifically the question of injury outcome of aircraft occupants. Outcome is related to the crashworthiness of the aircraft. Crashworthiness is the ability of an aircraft to provide protection during impact conditions. While great effort has gone into designing crashworthiness into some modern aircraft, others have received little design crash protection. Injury outcome correlates directly with the success of the crashworthy design. Many of the principles behind a successful design were discussed in the previous two lectures. These principles need to be understood by the investigating medical officer.

The approach to assessing injury outcome was alluded to previously and is used by many medical crash investigators. The "CREEP" acronym is a reference tool that defines this approach. The CREEP approach systematically analyzes the container, restraint system, environment, energy absorption features, and post-impact factors in order to determine injury outcome. This determination will be the medical officer's most important contribution to the accident board. In order to effectively assess CREEP factors, an understanding of the impact forces acting on the aircraft and occupants must be obtained.

CRASH VECTOR ANALYSIS

As described in the previous lecture, when an aircraft strikes the ground during an accident, the aircraft experiences an opposing force of very short duration (impact). This force compels the aircraft to change its velocity, reducing the initial speed to a final speed that will eventually be zero. The peak magnitude of this opposing force will depend on the length of time the force can act. If the time available is short, a higher peak force will result compared to when time available is longer. For example, a pilot who lands an aircraft and decelerates with full braking to a stop will feel a relatively high forward force. Alternatively, if the pilot lands and coasts to a stop without using brakes, a much lesser force will be felt. The final result is the same - the aircraft stops. The difference is the length of time the decelerating force is applied and hence, the peak magnitude of the force.

During an aircraft impact, "work" is applied by the earth (or ground structures) to the aircraft that diminishes the kinetic energy of the aircraft to zero. If it is assumed that the decelerating force is constant over the distance of work (which it is not), it is possible to picture the material response of the aircraft to the impact. Aircraft materials respond mechanically to the forces in a manner that depends on magnitude and direction of the force. Individual aircraft structures can distort short of failure (ie. a bent landing gear), to failure (ie. wing torn off), or well past failure to the point of total structural disruption/disintegration. With total structure failure, flammable fluids can be liberated, misted and ignited. The final resting condition of the aircraft depends on the material response to all of the forces acting on the aircraft during the impact.

Another way of thinking of this force is by considering acceleration. Force and acceleration vary

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directly when mass is constant (a reasonable assumption most of the time). Therefore, we can think of acceleration as directly related to force. Acceleration is often expressed as a ratio to the acceleration of gravity ("G"). G is commonly used in describing human tolerance.

Fundamental to the assessment of injury outcome is the calculation of magnitude and direction of the G experienced by the human occupant at impact. Knowing G at impact, a comparison can be made with known human tolerance data in order to assess the severity of whole body deceleration.

CRASH LOAD CALCULATIONS

While the investigating medical officer may not be expected to calculate the direction and magnitude of crash forces (or impact G), an appreciation of the process is important. To calculate these forces, it is necessary to know:

1. Initial and end velocities of each impact (primary and secondary).

2. Vertical stopping distances (depth of marks/gouges in the earth, extent of vertical damage to the aircraft, stroking of energy attenuation devices such as oleo struts and seats).

3. Horizontal stopping distances (length of marks/gouges in the earth, extent of airframe horizontal damage, rearward displacement of aircraft components).

4. An estimate of the shape of the deceleration force-time pulse specific to the accident.

PROBLEM SOLVING

The following approach to calculating crash force vectors is suggested:

1. Ensure consistency of units.

2. Draw a large diagram and label every known distance, velocity, and angle including terrain angle and aircraft attitude on impact.

3. Estimate the acceleration pulse or pulse possibilities and the final velocity.

4. Resolve the vertical and horizontal component velocities with respect to the earth.

5. Calculate vertical and horizontal accelerations (using the equations appropriate to the estimated crash pulses (Annex A).

6. Resolve the resultant acceleration vector with respect to the aircraft from component vertical and horizontal acceleration with respect to the earth.

7. Calculate the time of the acceleration pulse (using equations appropriate to the estimated pulse (Annex A)).

8. Estimate severity in terms of whole body acceleration by using human tolerance charts.

The central questions that these estimates try to answer are: 1) What was the expectation of survival in the crash? 2) If the answer is "unlikely", then detailed assessment of crash protection may not be a priority of the investigation. 3) If the answer is "likely", and the aircraft occupants were seriously or fatally injured, then how were the injuries caused? Assessment using the CREEP reference tool should then become a high priority of the investigation.

CRASH SURVIVABILITY

CREEP is a reference tool that describes an approach to survivability analysis. CREEP stands for:

C = Container

R = Restraints

E = Environment

E = Energy absorption

P = Postcrash factors.

THE CONTAINER

The term container describes the compartment/cockpit space that surrounds the aircraft occupant. A perfect container would completely protect occupants from incursions of outside materials/debris during the impact. During helicopter crashes, rotor blades may penetrate the aircraft container and cause injuries. Deformations of the container that reduce survivable space can cause injury and death. Restitution of container structures following impact can lead to the mistaken observation that survivable space was not compromised. Penetrating bird strikes are a relatively common form of container compromise that causes accidents.

THE RESTRAINT SYSTEM

A frequently employed restraint system has '5-points', or 5 points of attachment with a waist-level release device. The 5-point system consists of two shoulder straps, a waist strap that fits securely over the anterior superior iliac spines, and a central tie-down strap that holds the waist strap in place during deceleration. However, 4-point (waist and shoulder straps), and 2-point (waist strap only) systems are also used.

Evaluation of injury outcome should include understanding the interaction of the occupant with the aircraft through the restraint system. Injuries should be evaluated with respect to forces applied by restraining systems. Any accident investigation must include a comprehensive evaluation of the complete restraint system.

THE ENVIRONMENT

In the presence of tolerable whole body decelerating forces, a well restrained occupant in a perfectly preserved container can nevertheless be seriously injured by environmental hazards. The impact environment contains forces sufficient to decelerate an occupant from the initial aircraft velocity to a final velocity. These forces will apply over the whole body, and also the segments of the body with various degrees of restraint. The effect of these forces on body segments will vary, as will injury patterns. Thus, a chest decelerating into a restraint harness will experience a different injury force than a head decelerating into a control surface. During impact, poorly attached bulkhead-mounted equipment such as radar units or fire extinguishers can become detached and cause injury.

ENERGY ABSORPTION

By absorbing energy during impact, the aircraft effectively increases the distance (and time) through which the occupant decelerates, thereby decreasing the peak crash force experienced. If the aircraft is designed to be rigid, deceleration of the occupant seat will closely match deceleration of the aircraft and little energy attenuation will occur. If the aircraft crushes in a controlled manner, acceleration distance is increased and crash force decreases. Honeycomb construction, stroking seats, helmets, collapsible landing gear and landing strut systems are a few design features that can facilitate energy absorption. Landing gear that can accommodate a sink rate of 35 feet per second during stroke are present in some aircraft.

POSTCRASH FACTORS

The assessment of postcrash factors is very broad, encompassing all of the hazards attendant at a crash and survival site. There are myriad postcrash factors influencing survivability. These hazards can include physical obstacles that impede escape, such as poorly designed and placed seating arrangements, or difficult-to-open emergency exits. Fire byproducts can poison the cabin atmosphere, quickly incapacitating occupants. Unstowed baggage or a direct fire threat can cut off escape. Survival against the elements in remote locations is a very important concern that has prompted much research into methods of enhancing warm and cold survival on land and sea. The role of life support equipment, including the ejection seat, water survival gear, and environmental clothing needs critical assessment. More than one aviator has survived the crash, only to drown or freeze because of inadequate protective equipment. The role of emergency rescuers needs to be assessed - did the emergency plan and execution enhance or detract from survivability? Was training a factor? Did communications, or lack of communications, contribute to the problem? Were proper medical decisions made?

PUTTING IT TOGETHER

The bottom line of any medical investigation of an aircraft accident is determination of the cause and consequence. Assessment of the consequence involves the central issue of injury outcome. Assessment of outcome can be conducted systematically by first estimating the crash forces that would have been experienced by each of the occupants. An understanding of these forces within the context of the occupant's seated position and activities should allow a full assessment of outcome utilizing the CREEP reference tool. In the presence of "likely" survivable decelerating forces, any injury or death should be explainable in terms of some combination of container, restraint system, environment, energy absorption, or post-crash factors. Future designs that exploit the lessons learned from systematic analysis will lead to enhanced crashworthiness and improved survivability.

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ANNEX A

ACCELERATION PULSE SHAPES AND EQUATIONS (WITH RESPECT TO THE EARTH)

Definition:

V_o - initial velocity in feet per second
V_f - final velocity in feet per second
t - pulse duration in seconds
G - acceleration in Gs
S - acceleration distance in feet

I. Rectangular Pulse - Constant Deceleration:

$$\textit{Deceleration Force: } G = \frac{V_o^2 - V_f^2}{64.4S}$$

$$\textit{Pulse Duration: } t = \frac{V_o - V_f}{32.2G}$$

II. Triangular Pulses - Constantly Changing Deceleration:
Case A - Increasing Deceleration:

$$\textit{Decelertaion Force: } G = \frac{4V_o^2 - 2V_oV_f - 2V_f^2}{96.6S}$$

$$\textit{Pulse Duration: } t = \frac{2(V_o - V_f)}{32.2G}$$

Case B - Decreasing Deceleration:

$$\textit{Deceleration Force: } G = \frac{2V_o^2 + 2V_oV_f - 4V_f^2}{96.6S}$$

$$\textit{Pulse Duration: } t = \frac{2(V_o - V_f)}{32.2G}$$

Case C - Increasing and Decreasing Deceleration:

$$\textit{Deceleration Force: } G = \frac{V_o^2 - V_f^2}{32.2G}$$

$$\textit{Pulse Duration: } t = \frac{2(V_o - V_f)}{32.2G}$$

III. Half-sine Pulse - Constantly Changing Rate of Deceleration:

$$\textit{Deceleration Force: } G = \frac{.7854(V_o^2 - V_f^2)}{32.2S}$$

$$\textit{Pulse Duration: } t = \frac{1.57(V_o - V_f)}{32.2G}$$