SPECIAL STUDY

EMERGENCY LANDING TECHNIQUES IN SMALL FIXED-WING AIRCRAFT

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16. Abstract

This safety promotion study consolidates known techniques to increase survivability and reduce injuries in forced and precautionary landings in small fixed-wing aircraft. The study stresses the importance of reducing the main injury-producing factor, deceleration forces, and how to use the aircraft and terrain for this purpose. It describes emergency landing techniques for various flight and terrain conditions.

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FOREWORD

This study consolidates the lessons learned from past emergency landing experience in small, fixed-wing aircraft. The guidelines that are presented apply to the more adverse terrain conditions for which no practical training is possible. The need for this undertaking became apparent from the National Transportation Safety Board's statistical data which showed that about 25 percent of all general aviation accidents are associated with emergency landings.

It appears that the reliability of the modern airplane plays less of a role as a cause factor in emergency landings than pilot-induced factors such as flight planning, fuel management, and marginal weather. This comment is not intended as a reflection on the quality of training schools and regulatory provisions. The nature of general aviation is such that most pilots are on their own, once they are certificated; this means that they gain most of their later experience on a trial-and-error basis. Therefore, it is not unusual for a general aviation pilot to find himself in situations where his experience level provides no alternative but an emergency landing. Unfortunately, so much stress is being placed on "a suitable landing area" that some pilots will not even entertain the thought of a precautionary landing unless they can save the aircraft. Too many fatal weather accidents, classified as "maintained VFR in IFR conditions," undoubtedly resulted from desperate attempts to get through because the underlying terrain did not fit the pilot's mental picture of an emergency landing area.

It is the purpose of this study to explain how almost any terrain can be considered suitable for a survivable crash landing if the pilot knows how to use the aircraft structure to protect himself and his passengers. Hopefully, this knowledge will increase the number of those who can walk away from a difficult situation and benefit from the experience.

The guidelines in this study are intended to supplement rather than replace the emergency instructions in textbooks and aircraft owners' manuals; in case of conflict, the manufacturer's recommendentions should be followed.

THE AUTHOR

This paper was prepared by Gerard M. Bruggink, an Air Safety Investigator with the Bureau of Aviation Safety, National Transportation Safety Board.

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THE NATIONAL TRANSPORTATION SAFETY BOARD

The National Transportation Safety Board was created by the Department of Transportation Act of 1966. It is headed by five Members appointed by the President and approved by the Senate.

The Safety Board was established to improve safety in United States transportation extending to civil aviation, marine, pipeline, railroad, and highway modes of transportation. It has broad powers in the investigation and cause determination of transportation accidents. Through recommendations it is continuously involved in accident prevention and safety promotion. It is also responsible for reviewing on appeal the suspension, amendment, revocation, or denial of any certificate or license issued by the Secretary of Transportation or any modal Administrator.

In the field of civil aviation, the Safety Board conducts its own investigations of all air carrier and air taxi accidents, accidents involving large aircraft, midair collisions, and most fatal accidents. The Federal Aviation Administration, under delegation from the Safety Board, investigates all other accidents; however, as required by the act the Safety Board determines the cause of all aircraft accidents and reports the accidents to the public.

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I. TYPES OF EMERGENCY LANDINGS

For the purpose of this study the different types of emergency landings are defined as follows:

A. *Forced Landing:* An immediate landing, on or off an airport, necessitated by the inability to continue further flight. Typical example: an aircraft forced down by engine failure.

B. *Precautionary Landing:* A premediated landing, on or off an airport, when further flight is possible but inadvisable. Examples of conditions that may call for a precautionary landing: deteriorating weather, being lost, fuel shortage, gradually developing engine trouble.

C. *Ditching:* A forced, or precautionary, landing on water.

A precautionary landing, generally, is less hazardous than a forced landing because the pilot has more time for terrain selection and the planning of his approach. In addition, he can use power to compensate for errors in judgment or technique. Unfortunately, too many situations calling for a precautionary landing are allowed to develop into immediate forced landings when the pilot uses wishful thinking instead of reason, especially when dealing with a self-inflicted predicament. Such thinking probably played a role in some of the fatal accidents attributed to continued VFR flight into marginal weather. A low-flying pilot who is trapped in weather and does not give any thought to the feasibility of a precautionary landing, accepts an extremely hazardous alternative: inadvertent flight into an obstacle. He can improve his chances to survive an uncontrolled encounter only by timely slowing down.

II. PSYCHOLOGICAL HAZARDS

There are several factors that may interfere with a pilot's ability to act promptly and properly when faced with an emergency:

A. *Reluctance to Accept the Emergency Situation*

A pilot who allows his mind to become paralyzed at the thought that his aircraft will be on the ground in a very short time, regardless of what he does or hopes, severely handicaps himself in the handling of the emergency. An unconscious desire to delay this dreaded moment may lead to such errors as: failure to lower the nose to maintain flying speed, failure to lower collective to maintain rotor rpm (in helicopters), delay in the selection of the most suitable touchdown area within reach, and indecision in general. Desperate attempts to correct whatever went wrong, at the expense of aircraft control, fall into the same category.

B. *Desire to Save the Aircraft*

A pilot who has been conditioned during his training to expect to find a relatively safe landing area, whenever his instructor closed the throttle for a simulated forced landing, may ignore all basic rules of airmanship to avoid a touchdown in terrain where aircraft damage is unavoidable. Typical consequences: making a 180° turn back to the runway when available altitude is insufficient; stretching the glide without regard for minimum control speed in order to get into a better-looking field; accepting an approach and touchdown situation that leaves no margin for error. The desire to save the aircraft, regardless of the risks involved, may be influenced by two other factors: the pilot's financial stake in the aircraft and the certainty that an undamaged aircraft implies no bodily harm. As will be explained in this study, there are times when a pilot should be more interested in sacrificing the aircraft so that he and his passengers can safely walk away from it.

C. *Undue Concern About Getting Hurt*

Fear is a vital part of our self-preservation mechanism. However, when fear leads to panic we invite that which we want to avoid the most. A pilot who allows himself some choice in the selection of a touchdown point for a fully controlled crash has no reason to despair. The survival records favor those who maintain their composure and know how to apply the general concepts and techniques that have been developed throughout the years.

To summarize the role played by psychological hazards: it appears that the success of an emergency landing under adverse conditions is as much a matter of the mind as of skills.

III. BASIC CRASH SAFETY CONCEPTS

A pilot who is faced with an emergency landing in terrain that makes extensive aircraft damage inevitable should keep in mind that the avoidance of crash injuries is largely a matter of:

- Keeping vital structure (cockpit/cabin area) relatively intact by using dispensable structure (wings, landing gear, fuselage bottom, etc.) to absorb the violence of the stopping process before it affects the occupants.
- Avoiding forceful bodily contact with interior structure.

A. *Energy Absorption*

The advantages of sacrificing dispensable structure are demonstrated daily on the highways; a head-on car impact against a tree at 20 mph is less hazardous for a properly restrained driver than a similar impact against the driver's door. Accident experience shows that the extent of crushable structure between the occupants and the principal point of impact on the aircraft has a direct bearing on the severity of the transmitted crash forces and, therefore, on survivability.

Dispensable aircraft structure is not the only available energy absorbing medium in an emergency situation. Vegetation, trees, and even man-made structures, may be used for this purpose. Cultivated fields with dense crops, such as mature corn and grain, are almost as effective in bringing an aircraft to a stop with repairable damage as an emergency arresting device on a runway. Brush and small trees provide considerable cushioning and braking effect without destroying the aircraft. When dealing with natural and man-made obstacles with a greater strength than the dispensable aircraft structure, the pilot has to plan the touchdown in such a manner that only nonessential structure is "used up" in the principal slowing down process.

B. *Occupant Restraint*

The second requirement - avoiding forcible contract with interior structure - is a matter of seat and body security (seatbelt and shoulder harness). Unless the occupant decelerates at the same rate as the structure surrounding him, he will not benefit from its relative intactness but will be brought to a stop violently in the form of a so-called second collision. In case of partial restraint, such as the use of a seatbelt only, the same reasoning applies to the unrestrained body portions. A classic example in this respect is the frequency of head and chest injuries of car occupants who jackknife over the seatbelt in a severe front-end collision. The same injury mechanism has been responsible for fatalities in survivable aircraft accidents. Since so few light aircraft are equipped with shoulder harnesses, the pilot should try to minimize this hazard by avoiding a nose-first impact against solid obstacles; he should also make it a habit to insist on the routine use of seatbelts in his airplane.

C. *Speed and Stopping Distance*

The overall severity of a deceleration process is governed by speed (ground-speed) and stopping distance. The most critical of these is speed; doubling the groundspeed means quadrupling the total destructive energy, and vice versa. Even a small change in groundspeed at touchdown - be it as a result of wind or pilot technique - will affect the outcome of a controlled crash. For example: an impact at 85 mph is twice as hazardous as one at 60 mph; it is three times safer to crash at 60 than at 104 knots, (104-squared is about three times 60-squared). This is the main reason that pilots who are flying at treetop level in marginal weather are advised to slow to a comfortable airspeed when forward visibility is less than the minimum required for obstacle avoidance. It is also obvious that the actual touchdown during an emergency landing should be made at the lowest possible, but *controllable* airspeed, using all available aerodynamic devices (flaps, etc.).

Most pilots will instinctively - and correctly - look for the largest available flat and open field for an emergency landing. Actually, very little stopping distance is required if the speed can be dissipated uniformly, that is, if the deceleration forces can be spread evenly over the available distance. This concept is designed into the arresting gear of aircraft carriers that provides a nearly constant stopping force from the moment of hookup.

Since the typical general aviation aircraft is designed to provide protection in crash landings that expose the occupants to 9 times the acceleration of gravity (9 g's) in a forward direction, it is interesting to compare the minimum required stopping distances at various speeds, assuming that the crash deceleration takes place at a uniform 9 g's (see Figure 1). At 50 mph the required distance is 9.4 feet, while at 100 mph it is 37.6 feet (four times as long). Although these figures are based on an ideal deceleration process, it is comforting to know what can be accomplished in an effectively used short stopping distance. Understanding the need for a firm but uniform deceleration process in very poor terrain enables a pilot to select touchdown conditions that will spread the breakup of dispensable structure over a short distance, thereby reducing the peak deceleration of the cockpit/cabin area.

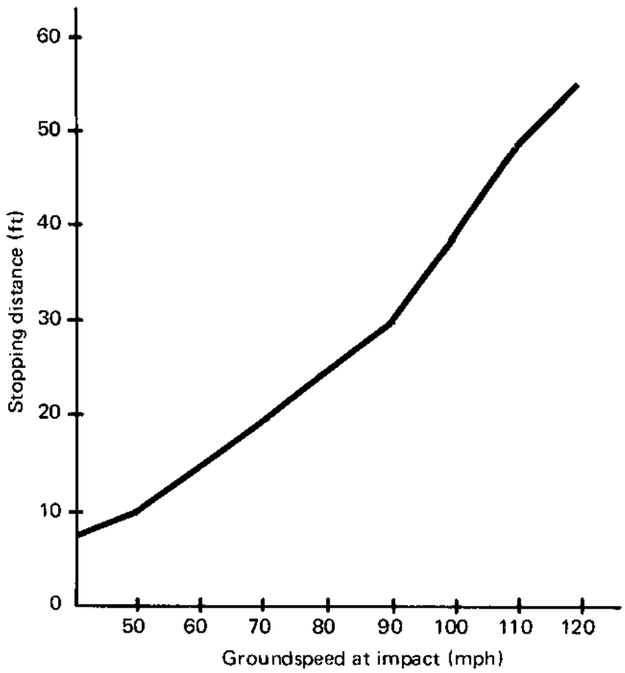

Figure 1. Stopping distance vs groundspeed during <u>uniform</u> 9-g deceleration.

D. *Attitude and Sink Rate Control*

The most critical - and often the most inexcusable - error that can be made in the planning and execution of an emergency landing, even in ideal terrain, is the loss of initiative over the aircraft's attitude and sink rate at touchdown. When the touchdown is made on flat, open terrain, an excessive nose-low pitch attitude brings the risk of "sticking" the nose in the ground. (Extreme examples of the destructiveness of such an occurrence are stall/spin accidents.) Steep bank angles just before touchdown should also be avoided; they increase the stalling speed and the likelihood of a wingtip strike.

Since the aircraft's vertical component of velocity will immediately be reduced to zero upon ground contact, it should be kept well under control. A flat touchdown at a high sink rate (well in excess of 500 feet per minute) on a hard surface can be injurious without destroying the cockpit/cabin structure, especially during gear-up landings in low-wing airplanes. A rigid bottom construction of these airplanes may preclude adequate cushioning by structural deformation. This characteristic, in combination with the rather limited human tolerance to vertical g's, has led to spinal injuries in extremely hard "pancake" landings. On the other hand, similar impact conditions may cause structural collapse of the overhead structure in high-wing airplanes. On soft terrain an excessive sink rate may cause digging-in of the lower nose structure and a severe forward deceleration.

Simulated forced landings, occasionally, lead to actual forced landings at a high sink rate when the engine fails to respond as anticipated. The habit of automatically raising the nose when the throttle is advanced for a go-around, without waiting for engine acceleration, can lead to destructive sink rates. It is advisable to maintain the proper approach speed and attitude until engine response is assured; this also applies to go-arounds from balked landings.

IV. TECHNIQUES

The "school solution" to an emergency that calls for a forced landing requires the following sequence of immediate actions:

- Maintain aircraft control (establish a glide at the proper speed).
- Select a field and plan an approach.

These actions may be combined with attempts to correct the emergency, especially when the pilot surmises the nature of the problem (carburetor heat, mixture, fuel selector, etc.). However, attempts to troubleshoot the cause of the emergency should be made only on a time-available basis. Under certain conditions the pilot may have a full time job just controlling the aircraft. When losing one engine of a light-twin during the critical takeoff phase, a pilot may not have more than a split second to decide what is best: relying on the performance charts, or his impulse to reduce power on the good engine to maintain controllability.

Concerning the controversial subject of turning back to the runway, following an engine failure on takeoff, each pilot should determine the minimum altitude at which he would attempt such a maneuver in his particular aircraft. Experimentation at a safe altitude should give the pilot an approximation of height lost in a descending, 180° turn at idle power. By adding a safety factor of about 25 percent he should arrive at a practical "decision height." It speaks for itself that the ability to make a "180" does not necessarily mean that the departure runway can be reached in a power-off glide; this depends on the wind, the distance traveled during the climb, the height reached, and the glide distance without power.

A. *Terrain Selection*

A pilot's choice of emergency landing sistes is governed by:

- The route he selects during the preflight planning.
- His height above the ground when the emergency occurs.
- His airspeed (excess airspeed can be converted into distance and/or altitude).

The only time that he has a very limited choice is during the low-and-slow portion of the takeoff; he should realize, however, that even under those conditions the ability to change the impact heading only a few degrees may insure a survivable crash.

When he is beyond gliding distance of a suitable open area, the pilot should judge the available terrain for its energy-absorbing capability, as explained earlier. If the emergency starts at considerable height above the ground he should be more concerned about first selecting the desired general area than a specific spot. Terrain appearances from altitude can by very misleading and considerable altitude may be lost before the best spot can be pinpointed. For this reason, the pilot should not hesitate to discard his original plan for one that is obviously better. However, as a general rule, he should not change his mind more than once; a well-executed crash landing in bad terrain can be less hazardous than an uncontrolled touchdown on an established field.

B. *Aircraft Configuration*

Since flaps improve maneuverability at slow speed, and lower the stalling speed, their use during final approach is recommended when time and circumstances permit it. However, the associated increase in drag and decrease in gliding distance call for caution in the timing and the extent of their application; premature use of flap, and dissipation of altitude, may jeopardize an otherwise sound plan.

A hard-and-fast rule concerning the desired position of a retractable landing gear at touchdown cannot be given. In rugged terrain and trees, or during impacts at a high sink rate, an extended gear would definitely have a protective effect on the cockpit/cabin area. However, this advantage has to be weighed against the possible side effects of a collapsing gear, such as a ruptured fuel tank. Manufacturer's instructions - if given - should be followed.

When a normal touchdown is assured, and ample stopping distance is available, a gear-up landing on level, but soft terrain, or across a plowed field, may result in less aircraft damage than a gear-down landing.

Deactivation of the aircraft's electrical system before touchdown reduces the likelihood of a post-crash fire. However, the battery master switch should not be turned off until the pilot no longer has any need for electrical power to operate vital systems (flaps, hydraulics, etc.). Positive aircraft control during the final part of the approach has priority over all other considerations, including aircraft configuration and cockpit checks. The pilot should try to exploit the power available from an irregularly running engine; however, to avoid unpleasant surprises during the touchdown phase it might be best to switch the engine and the fuel off just before touchdown. This not only insures the pilot's initiative over the situation but a cooled-down engine reduces the fire hazard considerably.

C. *Approach*

When the pilot has time to maneuver, the planning of the approach should be governed by three factors:

- Wind direction and velocity
- Dimensions and slope of the chosen field
- Obstacles in the final approach path

These three factors are seldom compatible. When compromises have to be made the pilot should aim for a wind/obstacle/terrain combination that permits a final approach with some margin for error in judgment or technique. A pilot who over estimates his gliding range may be tempted to stretch the glide across obstacles in the approach path (trees, powerlines, etc.). For this reason it is sometimes better to plan the approach over an unobstructed area, regardless of wind direction. Experience shows that a collision with obstacles at the end of a ground roll, or slide, is much less hazardous than striking an obstacle at flying speed before the touchdown point is reached.

No specific rules can be given for the pattern to be flown; there may not even be time to set up a pattern. The most important consideration is to get into such a position with regard to the selected spot that it can be reached by using normal techniques such as playing the final turn (turning in early or late, depending on altitude), slipping, and moderate S-turns. If considerable altitude has to be lost while over or near the chosen field, it should be done in such a manner that the field remains within gliding distance; speed control during all maneuvers is vital.

D. *Touchdown*

The importance of having control over the aircraft's attitude and sink rate at touchdown has already been explained. Since an emergency landing on suitable terrain resembles a situation with which the pilot should be familiar through his training, only the more unusual situations will be discussed.

1. *Confined Areas*

The natural preference to set the aircraft down on the ground should not lead to the selection of an open spot between trees or obstacles where the ground cannot be reached without making an "auto-rotative" descent; this option should be left to pilots of rotary-wing, STOL and VTOL aircraft.

Once the intended touchdown point is reached, and the remaining open and unobstructed space is very limited, it may be better to force the aircraft down on the ground than to delay touchdown until it stalls (settles). An aircraft decelerates faster after it is on the ground than while airborne. Thought may also be given to the desirability of ground-looping or retracting the landing gear in certain conditions.

A river or a creek can be an inviting alternative in otherwise rugged terrain. The pilot should insure that he can reach the water or creek-bed-level without snagging his wings. The same concept applies to road-landings with one additional reason for caution; man-made obstacles on either side of a road may not be visible until the final portion of the approach. Road traffic must be given priority.

When planning the approach across a road, it should be remembered that most highways, and even rural dirt roads, are paralleled by power or telephone lines. Only a sharp lookout for the supporting structures, or poles, may provide timely warning.

2. *Trees (Forest)*

Although a tree landing is not an attractive prospect, the following general guidelines will help to make the experience survivable:

- Use the normal landing configuration (full flaps, gear down).
- Keep the groundspeed low by heading into the wind.
- Make contact at minimum indicated airspeed, but noc below stall speed and "hang" the aircraft in the tree branches in a nose-high landing attitude. Involving the underside of the fuselage and both wings in the initial tree contact provides a more even and positive cushioning effect, while preventing penetration of the windshield.
- Avoid direct contact of fuselage with heavy tree trunks.
- Low, closely spaced trees with wide, dense crowns (branches) close to the ground are much better than tall trees with thin tops; the latter allow too much free-fall height. (A free-fall from 75 feet results in an impact speed of about 40 knots, or 4,000 feet per minute.)

- Ideally, initial tree contact should be symmetrical, that is, both wings should meet equal resistance in the tree branches. This distribution of the load helps to maintain proper aircraft attitude; it may also preclude the loss of one wing, which invariably leads to a more rapid and less predictable descent to the ground.
- Always aim for the softest and, when possible, the lowest part of a tree or tree line. Judge trees by their ability to slow the aircraft's forward speed in the same manner as a firefighter's safety net catches falling people.
- If heavy tree trunk contact is unavoidable, once the aircraft is on the ground, it is best to involve both wings simultaneously by directing the aircraft between two properly spaced trees. Do not attempt this "maneuver" while still airborne, as recommended in some textbooks.

3. *Mountainous Terrain*

The variety and irregularity of mountainous terrain makes it impossible to list general rules. The pilot should learn to instinctively avoid situations where an emergency would leave him without any choice; flying needlessly low and slow over cragged terrain is an example of such a situation.

In mountainous terrain only a short glide may be sufficient to bring the aircraft over lower lying terrain, thereby increasing effective altitude and terrain choice; maintaining a comforable cruise speed will assure the pilot of this advantage.

Slope landings should be made upslope whenever possible, with due consideration for the terrain conditions at the end of the slope. Avoid a situation where an excessive roll, or slide, would bring the aircraft to a sharp dropoff. When landing on a pronounced upslope, enough speed should be maintained to change the aircraft's descending flightpath, just before touchdown, into a climbing one that approximately parallels the slope. (Note: A descent at 50 knots and 500 feet per minute results in a 6° flightpath. In combination with an approach to a 24° upslope, an uncorrected 6° flightpath would lead to a ground "impact" angle of 6° + 24° = 30°.)

4. *Water (Ditching)*

A well-executed water landing probably involves less deceleration violence than a poor tree landing or a touchdown on extremely rough terrain. The reason for the apparent reluctance of some pilots "to take to the water" when there are no suitable alternatives may be the certainty of losing the aircraft or the fear of getting trapped. Actually, a fixed wing aircraft that is ditched at minimum speed and in a normal landing attitude will not sink like a rock upon touchdown. Intact wings and fuel tanks (especially when empty) provide flotation for at least several minutes even if the cockpit may be just below the waterline in a high-wing aircraft.

When considering the feasibility of ditching, the following factors should be taken into account:

- The water temperature and the estimated time to be spent in the water. (The survival time in water with a temperature of 33°F is less than one hour for the average person.)
- The proximity to land.
- The physical condition of the occupants and their ability to swim.
- The availability of lifevests and other water-survival equipment.
- The number of occupants and the number of usable exits.

Loss of depth perception may occur when landing on a wide expanse of smooth water, with the risk of flying into the water or stalling-in from excessive altitude. To avoid this hazard, the aircraft should be "dragged in" when possible. Use no more than intermediate flaps on low-wing aircraft; the water resistance of fully extended flaps may result in asymmetrical flap failure and slewing of the aircraft. Keep a retractable gear up. Insist that all occupants keep their restraint systems fastened until the aircraft has come to a complete stop; this insures impact protection and prevents disorientation with respect to the nearest exit location, regardless of aircraft attitude and light conditions. Ditching downstream in a swift running river has the same effect as a headwind, it reduces the relative groundspeed.

5. *Snow*

A landing in snow should be executed like a ditching, in the same configuration and with the same regard for loss of depth perception (white-out) in reduced visibility and on wide open terrain. An even snow layer, several feet thick, may blanket smaller obstructions and make otherwise rough terrain more suitable; pronounced "humps" that may hide larger obstructions should be avoided.

E. *Survival and Rescue*

The scope of this study precludes a discussion of the actions to be taken to insure survival and rescue following an emergency landing; in addition, considerable literature is available on this subject from various sources. For this reason, only some general guidelines are repeated:

- The filing of a flight plan not only insures prompt response from search organizations but it directs the search toward the most likely area.
- Search efforts are aimed at locating the aircraft; make it as conspicuous as possible and stay near it, unless you have compelling reasons to abandon it. Keep in mind that smoke is an international attention-getter.
- If the aircraft is destroyed, or inaccessible, you will have to work with whatever you happen to carry in your pockets; when flying over remote and unfriendly terrain, keep the minimum essentials on your person, such as waterproof matches and a pocketknife.
- Basic life support supplies should be carried in the aircraft as protection against extreme temperatures; when appropriate, warm clothing in the winter and water when making a summer desert crossing.

V. CONCLUSION

The basic message of this study can be summarized as follows:

A pilot who knows his aircraft and understands the what and why of the techniques that will insure a survivable emergency landing under adverse conditions has no reason for morbid preoccupation with the possibility of being forced down. The peace of mind associated with this knowledge should improve the pilot's overall performance which, in turn, may prevent an emergency or benefit its outcome.

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