FLIGHT SAFETY FOUNDATION
HELICOPTER SAFETY
Vol. 25 No. 2 | For Everyone Concerned with the Safety of Flight | March–April 1999

Simulator-based Study of Emergencies Yields Insights into Pilots' Reaction Times

The U.K. Civil Aviation Authority has recommended a review of helicopter-certification regulations to define realistically pilot-reaction time. During simulated training sorties, pilots immediately detected failures involving variables within their focus of attention, but required more time to detect alerting cues outside their focus of attention.

FSF Editorial Staff

Rotorcraft-certification standards of the Joint Aviation Requirements (JARs) in Europe and the Federal Aviation Regulations (FARs) in the United States generally specify that a helicopter be operable under normal and emergency conditions using normal pilot skills; that is, aircraft may not require exceptional piloting skill, strength or alertness during certification.

Thus, compensation for pilot-reaction time is an important safety factor in the design and certification of helicopters. Some researchers also believe that objective measurements — to isolate pilots' detection-and-reaction processes from any particular type of helicopter — would increase safety.

Research that compared pilot performance in three helicopter simulators has prompted the U.K. Civil Aviation Authority (CAA) to recommend a review of regulations for the certification of helicopters to consider new reaction-time data.[1] More realistic, operationally defined components of pilots' "detection time" and "total reaction time" also would help ensure that pilots can recover from time-critical emergencies even if they perform at the slow end of the normal range of pilot performance, said the CAA's report.

"Current civil requirements specify a 'corrective-action time delay' of one second (s) or 'normal pilot-reaction time' (whichever is greater) for the case of engine failure in the cruise," said the report. "This is commonly interpreted as a one-second time delay in the cruise, however 0.3 s is typically used for other flight phases. The term 'corrective-action time delay' is generally equivalent to the period between failure onset and the first movement of the appropriate control, referred to as detection time in this report. This time delay is clearly inconsistent with the results [of this study] and should be reviewed in light of the data presented.

"Depending, probably, on the urgency of the emergency, mean[2] total reaction times generally lie in the range two [seconds] to four seconds. Although these mean values represent what can reasonably be expected, design criteria should take account of normal, below-average performance. … [Regarding total power failure,] aircraft designers and certifiers should consider not mean reaction times but the tail of the distribution, i.e., those pilots whose total reaction times are longer than average without being abnormal. The 90th percentiles fall in the range 4.4 [s] to 5.7 s (2.07 [s] to 2.95 s for detection time). If the 90th percentile is an acceptable upper bound for reaction time, then a value of about six seconds for total reaction time [assuming no distraction] and three seconds for detection time would seem to be the appropriate criteria to adopt for design and certification purposes."

The research was conducted in response to three recommendations from investigations of helicopter accidents that occurred in 1981, 1986 and 1992 in the United Kingdom.[3] The purpose was to provide more detailed information on which to base future recommendations regarding helicopter-certification requirements.

One of these accident reports said, "The reaction time of a pilot following a total loss of power is critical. The rate of decay to a dangerously low [rotor rpm (NR)] of the [Aerospatiale] AS 355 F1 rotor, like that of other types of helicopters, exceeds the average pilot's reaction time. Cockpit indications of power loss in the AS 355 F1 are considered to be inadequate for single-pilot [instrument flight rules (IFR)] operations."[4] One of the report's recommendations said, "A review of those [British Civil Airworthiness Requirements (BCARs)] which deal with power-unit malfunctions [should] be conducted with a view to improving those indicating systems that enable a pilot to identify a failed power unit correctly."

"Although these mean values represent what can reasonably be expected, design criteria should take account of normal, below-average performance."

Another of these accident reports said, "The BCARs relating to helicopter main-rotor behavior following total power loss should be reviewed. The review should consider the latest data on pilot response times, the practicability of requiring all helicopters to be fitted with a rotor-speed-decay warning system, and means by which rotor-decay rates might be reduced."[5]

The CAA report also said that for one section of the requirements — regarding automatic flight control system (AFCS) anomalies under IFR — advisory material indicates that corrective-action times ranging from 0.8 s to 3.9 s are appropriate, depending on the phase of flight. These times and the data from CAA's study were relatively consistent. Nevertheless, the report recommended an overall review of regulations.

Data also appear to show that helicopter pilots respond most quickly when their attention already is focused on a continuous control task, said the report. The researchers said that little improvement in detection times may be possible, except by presenting cues more rapidly — for example, providing warning systems if alerting cues are relatively difficult to detect.

"Detection times for cyclic[-control] responses to AFCS runaways in the hover were smaller than those for collective [-control] responses to total power failures and tail-rotor failures," said the report. "AFCS runaways in the cruise and all the other failures represent a more general case, where the pilot's attention is not so focused on the critical element. The cyclic and collective response data for these cases indicate that mean detection times of one [second] to 2.5 s can reasonably be expected."

Regulations Show Context for Study

The following excerpts from airworthiness standards in JARs/FARs 27 (small rotorcraft/normal-category rotorcraft) and JARs/FARs 29 (large rotorcraft/transport-category rotorcraft) are representative of the current approach to regulations relevant to pilots' detection and reaction times (FSF editorial note: Italics added for clarity):

- JARs/FARs 27.141 and 29.141 — "The rotorcraft must … (b) Be able to maintain any required flight condition and make a smooth transition from any flight condition to any other flight condition *without exceptional piloting skill, alertness, or strength* … ;"

- JARs/FARs 27.231 and 29.231 — "The rotorcraft must have satisfactory ground-[handling characteristics] and water-handling characteristics, including freedom from uncontrollable tendencies in any condition expected in operation;"

- JARs/FARs 27.1581 (a) and 29.1581 (a) — " … A Rotorcraft Flight Manual must be furnished with each rotorcraft, and it must contain … (2) Other information that is *necessary for safe operation because of design, operating, or handling characteristics;"*

- JARs/FARs 29.55 (c) — "Determination of the [takeoff decision point (TDP)] must include the *pilot recognition-time interval* following failure of the critical engine;"

- JARs/FARs 27.143 (d) and 29.143 (d) — "The rotorcraft, after (1) failure of one engine, in the case of multi-engine rotorcraft that meet Transport Category A engine-isolation requirements, or (2) complete power failure in the case of other rotorcraft, must be controllable over the range of speeds and altitudes for which certification is requested when such power failure occurs with maximum continuous power and critical weight. No *corrective-action time delay* for any condition following power failure may be less than (i) For the cruise condition, *one second*, or *normal pilot-reaction time* (whichever is greater); and (ii) For any other condition, *normal pilot-reaction time;*"

- JARs/FARs 29.1309 (c) — "Warning information must be provided to *alert the crew to unsafe system operating conditions and to enable them to take appropriate corrective action … ;*"

- JARs/FARs 27.1329 (d) and 29.1329 (d) — "The [automatic pilot] system must be designed and adjusted so that … [the system] cannot … create hazardous deviations in the flight path, under any flight condition … in the event of a malfunction, *assuming that corrective action begins within a reasonable period of time;*"

- JARs/FARs 27.672 (a) and 29.672 (a) — "A warning which is clearly distinguishable to the pilot under expected flight conditions *without requiring the pilot's attention* must be provided for any failure in the stability-augmentation system [SAS] or in any other automatic or power-operated system which could result in an unsafe condition if the pilot is unaware of the failure. … ;"

- JARs/FARs 27.672 (b) and 29.672 (b) — "The design of the [SAS] or of any other automatic or power-operated system must allow initial counteraction of failures *without requiring exceptional pilot skill or strength* … ;" and,

- Appendix B to JARs/FARs 27 VII. (b) and 29 VII. (b) — "The SAS must be designed so that it cannot create a hazardous deviation in flight path … in the event of malfunction or failure, *assuming corrective action begins within an appropriate period of time* … ."

Researchers Define Variables To Measure Reaction Time

The CAA report said that past experimental research into pilot-reaction times to emergencies in helicopters often has been limited in applicability to actual flight conditions, and in using definitions without objective measurement criteria.

"Current regulations use a variety of terms, such as recognition time and decision time, which are not operationally defined," said the report. "A necessary methodological step, therefore, is the development of suitable definitions. Unfortunately, in comparison with the extensive and detailed laboratory studies of reaction times, there has been little work examining reaction times in real-life situations."

The report defined variables as follows (FSF editorial note: Italics added for clarity): "*Detection time* was defined as the interval between failure onset and the initiation of a response. *Response time* was defined as the period from initiation to completion (where completion was identifiable). *Total reaction time* was defined as the detection time plus the response time." The report said that these terms do not correspond with terminology used in current regulations; nevertheless, they enable objective measurements.

"Unfortunately, in comparison with the extensive and detailed laboratory studies of reaction times, there has been little work examining reaction times in real-life situations."

Measurement of the beginning of corrective control response to each simulated anomaly was defined as "the first noticeable deviation from steady state or, if the control was traveling in the wrong direction, the point of [control] reversal was used."

The study focused on three time-critical emergencies — total power failure, tail-rotor-control failure and tail-rotor-drive failure — and on AFCS failures, involving situations that may be time critical. Civilian pilots and military pilots involved in the study were not aware that their training sorties were being recorded by researchers, with the exception of one trial; permission to use the simulator data was granted by others responsible for the training to avoid causing any effect on pilots' normal performance. The pilots included:

- Twenty-four U.K. Royal Air Force pilots whose responses were measured during total power-failures in a simulator for the Boeing Vertol Chinook HC.Mk 1 twin-turbine helicopter;

- Ten civilian pilots whose responses were measured during total power failures in a simulator for the Sikorsky S-61N twin-turbine helicopter;

- An unspecified number of civilian pilots whose responses were measured during total power failures, tail-rotor-control failures and tail-rotor-drive failures in a simulator for the Eurocopter (formerly Aerospatiale) AS 332 Super Puma twin-turbine helicopter; and,

- Sixteen civilian pilots exposed to AFCS runaways and total power failures in the S-61N simulator.

Each of the three simulators had a six-axis motion platform and a dusk/night visual system. Data generated by simulator software at the highest possible sampling rates indicated the onset of a failure (or in some trials, an equivalent variable for actual failure, such as the start of data recording) and the initiation of pilot response. The researchers also analyzed visual, auditory and motion cues; instrument indications; ambient noise and frequencies; and linear accelerations for supplemental information.

A cockpit video recording was made of each failure scenario to prepare a timeline of events as they would occur without any pilot intervention. These recordings showed that a total power failure would become unrecoverable in 10 s for the S-61N, in 3.8 s for the Chinook and in 5.4 s for the Super Puma.

Fast Detection/Reaction Times Correlated with Recoveries

"There were insufficient data on outcome (recovered/crashed) to permit analysis for the S–61N and the Super Puma," said the report. "Of the 30 Chinook exposures for which outcome data existed, 26 pilots successfully recovered from total power failure and four failed to recover. Failures from which the pilots recovered involved significantly shorter response times than those which resulted in crashes, but detection times were not significantly different. … The pattern of [responses by three of the pilots who failed to recover in the simulation] did, however, appear qualitatively different from the vast majority of the remainder [that is, the 22 pilots who recovered] in that the collective movement was not a simple, rapid reduction in demand, but incorporated reversals or hesitations."

The report said that auditory cues probably were the most significant alerting stimuli in each type of helicopter, and some differences in detection times correlated with the degree to which auditory cues were "attention getting."

Pilots' Reaction Times Showed Some Variation

Detection and reaction times varied significantly among the pilots observed, but performance generally was within expected ranges. Nevertheless, the report said that the performance of the 90th percentile of pilots — not average performance — should provide the basis for regulations. The following data were recorded:

- Measurements after total power failure in the Chinook simulator showed mean detection time of 1.07 s, mean response time of 1.24 s and mean total reaction time of 2.3 s. The corresponding values for the 90th percentile of pilots were 2.07 s, 2.28 s and 4.42 s.

- Measurements after total power failure in the S-61N simulator showed mean detection time of 1.67 s, mean response time of 1.61 s and mean total reaction time of 3.33 s. The corresponding values for the 90th percentile of pilots were 2.53 s, 3.85 s and 5.72 s.

- Measurements after total power failure in the Super Puma simulator (in trials that did not involve a distracting alternator failure) showed mean detection time of 2.22 s, mean response time of 1.82 s and mean total reaction time of 4.13 s. The corresponding values for the 90th percentile of pilots were 2.95 s, 1.95 s and 4.73 s. The report said, "In the case of the Super Puma [simulator] data, it was sometimes difficult to determine with any confidence where the control movement ended. As a result, rather fewer response-time and total-reaction-time results are quoted than detection-time results. … A separate analysis on the Super Puma data … showed no significant effect on detection, response or total reaction times due to the presence of a distraction."

- Measurements after tail-rotor-control failure in the Super Puma simulator showed mean detection time of 0.9 s, mean response time of 1.53 s and mean total reaction time of 2.57 s. The corresponding values for the 90th percentile of pilots tested were 1.22 s, 3.78 s and 4.65 s. The report said that because some response times could not be determined confidently from some data, the 90th percentile figures for response time and total reaction time probably are slight underestimates;

- Measurements after tail-rotor-drive failure in the Super Puma simulator showed mean detection time of 1.53 s, mean response time of 2.74 s and mean total reaction time of 4.9 s. The corresponding values for the 90th percentile of pilots tested were 2.94 s, 6.06 s and 7.79 s. The report said that some response times could not be determined with confidence from some data, thus producing fewer data points on which to base these calculations.

- Measurements after two types of AFCS failures (each causing an uncommanded pitch-up) in the S-61N simulator were conducted differently. The data showed mean detection time during hover of 0.4 s and 90th-percentile detection time of 0.69 s. The mean detection time during cruise was 1.59 s and the 90th-percentile detection time was 2.4 s. These sorties also had a mean effective total reaction time[6] during hover of 1.62 s and a 90th-percentile detection time of 1.83 s. The mean effective total reaction time during cruise was 2.24 s and the 90th-percentile time was 2.61 s. The failures during these sorties were not accompanied by significant motion cues or changes in audio cues; visual cues primarily indicated each AFCS uncommanded pitch-up.

The researchers acknowledged and documented several limitations in their findings, including unexplained response characteristics, uncertain effects of simulator-motion cues, effects of repeating emergencies or controlling the order of emergencies, and difficulty measuring failure onset accurately in the Super Puma. For example, there was no evidence of significant linear accelerations (greater than 0.1 G) during total power failures or tail-rotor failures. Motion cues during AFCS uncommanded pitch-ups also were considered insignificant for purposes of the study.

When some simulated emergencies in the Super Puma were preceded by an alternator failure as a distraction factor, the distraction did not demonstrate a statistically significant effect although "there is some indication that a few pilots may have suffered a significant effect," said the report. Nevertheless, some general observations about average performance were made.

"It took pilots, on average, about one second to detect total power failure in the Chinook simulator and a similar time to respond to it," said the report. "S-61N and Super Puma pilots took significantly longer for detection and there was a trend towards slightly longer times for the response. Mean total reaction times were, as a result, one [second] to 1.8 s longer. … The results indicate the broad range of response times to be expected, and suggest that average total reaction times in the range of two [seconds] to four seconds should be expected in most circumstances."

The report said that both the type of emergency and the type of aircraft had an influence on pilot-reaction times, but that further study will be needed to sample and analyze a wider range of variables. For example, variation in pilots' detection time during hover compared to detection time during cruise flight was suggested as one avenue for further study.

"The cruise naturally demanded less continuous monitoring of flight variables than the hover, and this general reduction in [pilot] attentiveness seems to have had a more noticeable effect on detection time [in simulated AFCS failures] than the artificial distraction introduced for some total power failures in the Super Puma," said the report.

The report has been provided to the rotorcraft Performance and Handling Qualities Harmonization Working Group of the Joint Aviation Authorities and the U.S. Federal Aviation Administration. This group is reviewing JARs/FARs 27 and 29 engine-failure intervention-time criteria.♦

Notes and References

1. U.K. Civil Aviation Authority (CAA). "Pilot Intervention Times in Helicopter Emergencies." CAA Paper No. 99001. London, England. January 1999.

2. Mean refers to an average that is computed by dividing the sum of a list of values by the total number of values in that list.

3. U.K. CAA. The cited recommendations were Recommendation 4.4 of the Accidents Investigation Branch (AIB) Aircraft Accident Report 4/83 (accident to Westland Wessex 60 G-ASWI 12 miles east-northeast of Bacton, Norfolk on Aug. 13, 1981); Recommendation 4.3 of Air Accidents Investigation Branch (AAIB) Aircraft Accident Report 7/87 (accident to Twin Squirrel AS355 G-BKIH at Swalcliffe, near Banbury, Oxfordshire, on April 8, 1986); and Recommendation 92-26 of AAIB Accident Report EW/C92/2/4 (accident to Robinson R22M G-BPPC at Oldham in February 1992). The U.K. Department of Transport changed the name of the Accidents Investigation Branch to the Air Accidents Investigation Branch in 1987.

4. U.K. AAIB. *Report on the Accident to Twin Squirrel AS355 G-BKIH at Swalcliffe, near Banbury, Oxfordshire on 8 April 8 1986*. Aircraft Accident Report 7/87, Dec. 16, 1987, 28, 30. The report said, "The accident was caused when the helicopter, whilst flying at 2,500 feet in [instrument meteorological conditions], suffered a total loss of power and did not accomplish a normal autorotative descent and landing due to a significant decrease in rotor rpm. The most likely cause of the power loss was the ingestion of slush which had formed near the intake area of the engines. It was not possible to determine whether both engines failed simultaneously or in succession." The pilot and five passengers were killed and the aircraft was destroyed, said the report.

5. U.K. AIB. *Report on the Accident to Westland Wessex 60 G-ASWI 12 Miles ENE of Bacton, Norfolk, on 13 August 1981*. Aircraft Accident Report 4/83. Aug. 23, 1983, 36. The report said, "G-ASWI went out of control in the late stages of an autorotative descent and crashed into the sea with a very low rotor speed, all 13 men on board being killed. The reason for the loss of control could not be established." The aircraft was destroyed.

6. The response times and total reaction times could not be measured in a manner comparable to other trials in the study. Thus, "effective total time" to control the failure condition was defined as the interval between the first cyclic response and the reversal of the AFCS uncommanded pitch-up.

Visit our World Wide Web site at http://www.flightsafety.org

HELICOPTER SAFETY
Copyright © 1999 FLIGHT SAFETY FOUNDATION INC. ISSN 1042-2048

Suggestions and opinions expressed in FSF publications belong to the author(s) and are not necessarily endorsed by Flight Safety Foundation. Content is not intended to take the place of information in company policy handbooks and equipment manuals, or to supersede government regulations.

Staff: Roger Rozelle, director of publications; Mark Lacagnina, senior editor; Wayne Rosenkrans, senior editor; John D. Green, copyeditor; Karen K. Ehrlich, production coordinator; Ann L. Mullikin, production designer; Susan D. Reed, production specialist; and David A. Grzelecki, librarian, Jerry Lederer Aviation Safety Library.

Subscriptions: US$60 (U.S.-Canada-Mexico), US$65 Air Mail (all other countries), six issues yearly. • Include old and new addresses when requesting address change. • Flight Safety Foundation, Suite 300, 601 Madison Street, Alexandria, VA 22314 U.S. • Telephone: +1 (703) 739-6700 • Fax: +1 (703) 739-6708

We Encourage Reprints

Articles in this publication may, in the interest of aviation safety, be reprinted, in whole or in part, in all media, but may not be offered for sale or used commercially without the express written permission of Flight Safety Foundation's director of publications. All reprints must credit Flight Safety Foundation, *Helicopter Safety,* the specific article(s) and the author(s). Please send two copies of the reprinted material to the director of publications. These reprint restrictions apply to all prior and current Flight Safety Foundation publications.

What's Your Input?

In keeping with FSF's independent and nonpartisan mission to disseminate objective safety information, Foundation publications solicit credible contributions that foster thought-provoking discussion of aviation safety issues. If you have an article proposal, a completed manuscript or a technical paper that may be appropriate for *Helicopter Safety,* please contact the director of publications. Reasonable care will be taken in handling a manuscript, but Flight Safety Foundation assumes no responsibility for submitted material. The publications staff reserves the right to edit all published submissions. The Foundation buys all rights to manuscripts and payment is made to authors upon publication. Contact the Publications Department for more information.