Understanding the Role of HEMS in Emergency Care and Working to Reduce Accidents, Costs, and Transport Time

Project Number: MQF IQP 2814

An Interactive Qualifying Project

submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the

By

Aaron Durkee
Sydney Padula
Jeffrey Paquette

Submission Date – March 29, 2012

Professor M. S. Fofana, Advisor
Mechanical Engineering Department

Abstract

This paper comprises of three overarching objectives: to understand the helicopter emergency medical system (HEMS), to identify problems related to their use and operation, and to propose solutions to these identified problems. The areas of research consist of HEMS standards, monetary allocation associated with the HEMS program, landing areas and dispatch times, and factors that contribute to fatal and nonfatal helicopter crashes. The identified problems associated with helicopter costs are related to the high cost of obtaining and operating a helicopter under the EMS function, which is restrictive to both the program's use and expansion. Proposed solutions to the expenses include itemized cost-saving opportunities as well as potential future technologies that the program would benefit from adapting. Problems associated with helicopter landing zones and transport times are a lack of safe, documented landing points and inefficiencies regarding helicopter dispatch. Proposed solutions include a portable landing zone kit for deployment at the accident site to allow for safe landing and takeoff by the helicopter. Lastly, the problems associated with helicopter safety and crashes include human error, mechanical malfunction, and environmental effects. Solutions include providing additional weather information and isolating the piloting area from the medical compartment and creating codes similar to the ground ambulance crews to isolate the pilot's interaction with the stresses induced by trauma treatment.

Table of Contents

List of Figures

List of Tables

List of Equations

Acknowledgements

Most importantly, we would like to acknowledge professor, MIRAD Labs IQP advisor, and mentor Mustapha S. Fofana. His insight, knowledge, and understanding aided us greatly in the development of our work.

We would also like to acknowledge Neil P. Blackington, the Deputy Superintendent of Fleet Services for Boston EMS. Neil was present for a preliminary presentation of our findings and provided useful information that further refined our search for information and aided us in discovering new solutions to improve current HEMS operations

Chapter 1. Helicopter Emergency Medical Service and Life Saving Practices

1.1 Introduction

Medical helicopters are currently much more expensive and less efficient than current ground transport systems. Helicopters are used in situations where time is of great importance to the care of the patient, long distances must be traveled, or when ground crews are unable to reach the patient. The drawbacks are great, however, and inhibit the widespread use of helicopters as medical transport devices. The costs associated with acquiring and maintaining a fleet are multi-million dollar expenditures, meaning that many hospitals are unable to afford their use. Many areas lack the infrastructure for aircraft to takeoff and land, and buildings built to support helicopters require special structural considerations for increased stresses. Many landing zones are uncharted and unknown to operators, making the current infrastructure inefficient. Helicopters also create additional stresses for operators and patients during flight. Based on the speed of the aircraft, they consume more fuel, create extraordinary noise, vibrate excessively, and have a very limited space to operate and store necessary tools and medication. In this project we will gain an understanding of the procedures and operations that the helicopters undergo and find ways to make their services more accessible to the public by displaying cost-saving measure and increase efficiency.

Our goal is to gain an overall understanding of HEMS contributions in the field of emergency medicine. The objective of this project is to improve the effectiveness of HEMS operations with regards to costs, procedures, and safety. To accomplish our objectives we plan to investigate current HEMS operations and delve into the details surrounding how HEMS is utilized in current procedures. We also plan to reevaluate current landing zones and transport time and find alternate methods to more effectively accomplish those tasks. Overall, we plan to implement new strategies and operations that will make HEMS processes less financially demanding and safer for medical crews, pilots, and patients.

The following chapters will delve into understanding and improving the role of HEMS in conventional emergency care. In Chapter 2, attention will be given to HEMS's interaction with other aspects of emergency care, understanding when HEMS services are required over those of ground EMS is one area of interest. We will also see how costs, including the helicopter itself, fuel, maintenance, and other expenses affect HEMS availability, accessibility, and utilization. This section also looks at helicopter landing sites, both hospital-landing pads and in the field patient receiving locations, and how they are designed and operate. Lastly, this chapter investigates past HEMS accidents, covering on several areas including the various causes and whether such causes are avoidable. The third Chapter works toward improving HEMS operations so they may be more effective in saving lives. Through upgrading of crew requirements, addition of new equipment, as well as phasing out of old equipment, improvements will be made to enhance aid the patients receive. Other improvements less financially demanding are also explored here with regards to current practices, and ways in which these practices can be improved effectively and immediately. Chapter 4 presents the conclusion.

Chapter 2. Understanding HEMS and Patient Centric Quality Care

Section 2.1 Uses and Costs

Section 2.1.1 Prerequisites for Aerial Ambulance Use

Aerial ambulances are run as a division of an Emergency Medical Service (EMS) group and as such operate under the same standards of care as the common ground based ambulance. As such, it's important to understand the conditions that are necessary for the use of a ground-based ambulance before discussing the dispatching of an aerial ambulance.

Massachusetts general law, chapter 111C defines an ambulance as "any aircraft, boat, motor vehicle or any other means of transportation, however named, whether privately or publicly owned, which is intended to be used for, and is maintained and operated for, the response to and the transportation of sick or injured individuals[39]." Ambulances come in multiple variations, containing either basic life support (BLS) or advanced life support (ALS). These variations are determined by the level of training that the paramedics associated with the vehicle have obtained (either basic level, or intermediate and above) in conjunction with the service expected of, and equipment carried by the ambulance. These classes are associated with all ambulance vehicles, including the ground based and air based ambulances [1].

Ambulances are assigned tasks on a need basis as determined by a dispatcher that receives a 9-1-1 call. In the assignment, a dispatcher assesses the situation described by the caller and determines which course of action will provide the highest level of patient care. Thus, the dispatcher weighs the capabilities of the vehicles in their ambulance fleet against the requirements of the patient. Therefore, the capabilities of an air ambulance (classified as a Class IV ambulance in Massachusetts) must be understood.

Class IV ambulances may be modeled using the physical characteristics of the vehicle, the medical equipment contained within the craft, the crew that operating it, and the financial expenses that the craft produces. The exploration of these facets creates lists of the capabilities and the limitations of the class IV ambulance, making it possible to determine where the ambulances should and should not be used. The dispatcher must contain a solid knowledge of these capabilities and limitations in order to best provide medical care to the patient.

The physical characteristics of class IV ambulances vary between the craft used, and as such a table of these characteristics is well suited. The helicopters displayed are the EC 135, used by UMass Memorial Hospital's LifeFlight, and the EC 145 and S-76 C++, both used by Boston MedFlight.

Table 1 - Common HEMS Helicopters and Characteristics

Attribute	American Eurocopter EC135 [27]	American Eurocopter EC145 [26]	Sikorsky S-76 C++ [70]
Fast Cruise Speed (mph)	161	153	178
Range (miles)	394	426	472
Max Takeoff Weight (lbs)	6503	7903	11700
Empty Weight (lbs)	3208	3951	7005
Useful Load (lbs)	3296	3953	4695
Length (ft)	39.7	42.75	52.5
Width (ft)	8.7	7.87	10
Height (ft)	12.3	12.98	14.5
Rotor Diameter (ft)	33.5	36.09	44
Pass. Cabin			
Volume (ft^3)	173	166.43	204
Baggage Compartment Vol (ft^3)	173	46.72	38

By analyzing this table, it's possible to extract the strengths of the class IV ambulance. Due to the high speed and aerial nature of the class IV, the greatest strength is the speed at which the ambulance can reach its destination. This is due to the fact that time is the most important resource in determining the survival of a critically injured patient and how ambulances and Emergency Medical Technician (EMT) crews are incapable of advanced care and surgeries. The range is also a strength: aircraft can fly in a straight line to their destination as opposed to following the laid out infrastructure as ground based ambulances do. The usable volumes can be considered a strength as well, since some ground based ambulances, such as those based on the Mercedes-Benz Sprinter 144", have smaller cabins than the aircraft (the Sprinter 144" has 159 cubic feet available) [74].

The table makes it possible to discern limitations associated with the class IV ambulance as well. The largest limitation visible in the table is the total size of the ambulance. With the smallest of the 3 helicopters having a 33.5" rotor span, landing sites must be significantly larger to allow maneuvering about the craft as well as to maintain a high level of safety. The large weights of the aircraft are also a drawback; many structures are not made to support the large stresses that helicopters place upon them.

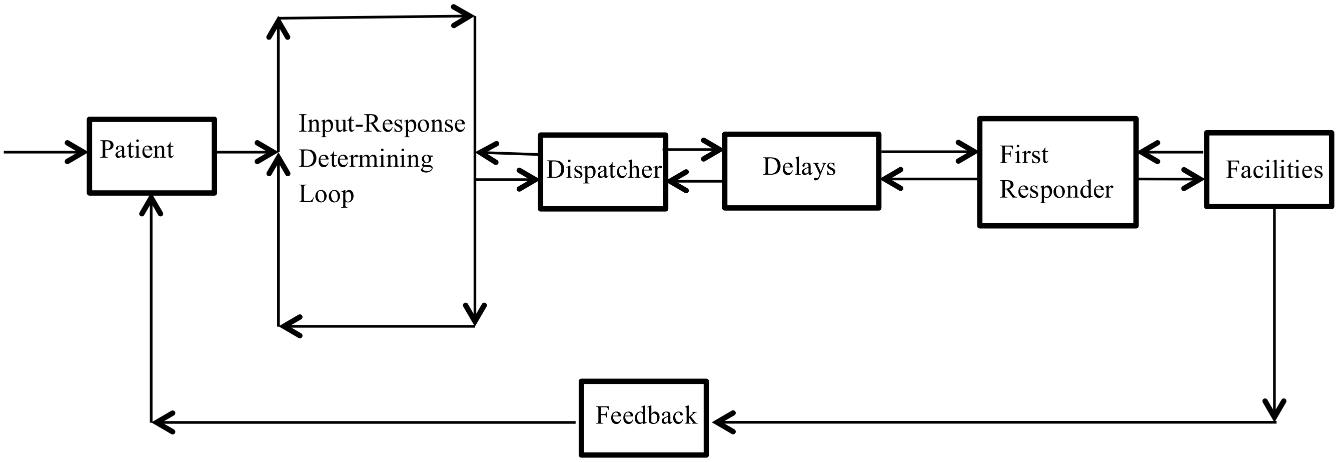
Class IV ambulances have different equipment requirements than other classes of ambulances, and as such they must be known to the dispatcher. In order to qualify as capable of providing BLS to patients, the requirements of class IV ambulances are less than other classes [62]. The requirements for providing ALS are consistent across all classes [62]. A table explaining the equipment requirements for BLS can be found in Appendix A, and a more in depth version can be found at the Office of Emergency Medical Services website in the Administrative Requirements Manual [62]. It should be noted that these are the minimums for operating an ambulance of a specific class and qualification, and not necessarily what each ambulance will contain as crews may add items, as they feel necessary.

Ambulance crews consist of EMTs of either an EMT-Basic, EMT-Intermediate, or EMT-Paramedic level of training corresponding to the level of care the ambulance is to provide. In order to staff a BLS class I, II, or V ambulance, at least two EMTs are required, both at least of the EMT-Basic level. In order to staff an ambulance at the ALS level, at least two EMTs are required, with one of them at the EMT-Intermediate level or higher. If a patient is to be transported in the ambulance that is receiving paramedic level care, one of the staff must have EMT-Paramedic training. In order to staff a class IV ambulance, a pilot and at least two EMTs are required, with one EMT being a registered nurse of at least the EMT-Basic level and the other being of at least EMT-Paramedic level. Both EMTs manning the aircraft must have special training in the emergency care services to be executed. If a patient with special needs is to be transported, a registered nurse, a physician's assistant, or a physician may replace the EMT-Paramedic level EMT [1]. Class IV ambulances require a higher trained staff than other ambulances, and are capable of providing a high level of care while dealing with the additional demands that helicopters produce.

Ambulances are expensive services to operate, and as for class IV ambulances prices can be an inhibitor to use. Ground based ambulances will cost patients several hundred dollars, but under a thousand dollars. Use of an aerial ambulance can cost patients between three and five thousand dollars [2]. These costs will often be covered by medical insurance, which is required of all citizens in Massachusetts, but some providers will not cover the cost and most will require a co-pay. Since there is no guarantee of coverage, the service runs a financial risk of the patient not being able to pay for the service in a timely manner, if at all. Aerial ambulances are also very expensive to purchase and maintain, which will be discussed in section 2.1.C. A dispatcher must keep the costs and associated value and risks in mind when calculating which ambulance to send as a response to a call.

The process of calling an emergency medical service and the corresponding response can be modeled using control theory as Professor M. S. Fofana has illustrated. Figure A displays a generalized version of the control system.

Table 2 – Dynamic Control System of Helicopter Emergency Medical Systems Operations



In between the dispatcher, delays, first responder, and the facilities there are a series of springs and dampers that represent resistance and delays in the system. The purpose of determining which ambulance to use is in order to minimize the difference in the feedback, which represents the service, provided compared to the ideal service the patient expects. In using an aerial ambulance, it's in order to reduce the resistance and delays between when the patient reports an incident and when the patient arrives at the correct facilities, such as a hospital or clinic. This in turn leads to an increase in patient medical care and a decrease in the difference between the feedback and the ideal patient experience.

The series of delays can be broken into 3 different portions: Network tolerance delays, paramedic drift delays, and vulnerability and uncertainty delays. The network tolerance delays are those associated with the communications between the involved parties, mainly the dispatcher and the responders. The network structure for the aerial ambulances and the ground-based ambulances are largely the same and are operated in the same manner. The only differences are in that helicopters have much greater environmental noise during use, and as such have the possibility of a greater delay due to miscommunication from background noise. Therefore, network tolerance delay isn't a factor that should be considered in determining whether to use a ground or an aerial based ambulance

Paramedic drift delays are the primary reason that a dispatcher would choose to send an aerial ambulance in place of its ground based counterpart. The drift delays are related to the transit time between where the EMTs are stationed and the area that they are being sent too. Helicopters are known for their speed, so a situation requiring an absolute minimum in drift delays would be ideal for helicopter use. Other factors of the drift delays are delays related to preparing for departure and loading the patient into the vehicle, which are not significantly different for ground based or aerial based ambulances.

The vulnerability and uncertainty delays are hard to account for due to their nature. These delays are encountered when factors that are not expected enter the scenario, such as a malfunction with the equipment or as a worst-case scenario when the ambulance experiences an accident. The reliability of the ground based and air based ambulances are such that neither experiences these delays often enough to determine that one should be used over the other due to these vulnerabilities and uncertainties.

The springs and dampers that are located between the dispatcher and the destination of the first responders represent disturbances that are encountered between these two points. These disturbances affect all the delays that are modeled between the two. Examples of disturbances such as these are weather, which affects wireless signal transmission as well as travel times, and vibrations, which may increase travel times due to a required decrease in speed to lower the amplitude of the vibrations as well as the resulting noise.

In summary, a dispatcher will choose between the use of an aerial ambulance and a ground based ambulance due to the particular strengths and weaknesses of each vehicle. The main strengths of the helicopter are a faster travel time, adequate medical materials onboard, and a highly trained team. The ground-based ambulance is stronger in that it allows flexibility of pickup point, a more comprehensive medical materials list, cheaper operation, and a flexibility of crew.

Section 2.1.2 Procedures and Regulations

Aerial medical ambulances are subject to procedures that regulate how the EMTs and pilots that crew the ambulance must act. These procedures are aimed to improve the level of patient care that is provided between the sites that the patient is retrieved and the destination. They achieve this by improving the level of safety by which the helicopter and crew operate and by providing a series of guidelines for care. It is by these guidelines that the methods by which care for the patient are developed.

In order to understand the procedures surrounding the operation of a helicopter EMS service, an exploration into the requirements of the helicopter and crew give important background. These regulations aim to guarantee the safety of the crew and patient during operation. The regulations provide grounds to determine the airworthiness of the aircraft as well as the minimum requirements for each specific set of patient needs.

The requirements for the aircraft are set forth by the Federal Aviation Regulations (FAR), Title 14, Part 135.25 [30]. This section requires that the aircraft is registered as a civil aircraft and carries a current airworthiness certificate issued in the country of registration. The regulations regarding airworthiness are provided in the FAR Title 14, Part 27. The regulations are split up according to flight characteristics, strength requirements, design and construction, power plant, equipment, and operating limitations and information. The airworthiness inspection procedure required to obtain a certificate is set for in Part 91.409 [31]. The requirements for airworthiness are such that the airframe, engines, propellers, rotors, appliances, survival equipment, and emergency equipment pass their respective inspections and have received all schedules maintenance as set by the manufacturer. The other clause that Part 135.25 requires is that the aircraft meets the requirements for the operation, in this case for ambulance use. These requirements are outlined for the state of Massachusetts in 105 CMR 170.000.

Noise is of particular concern when a helicopter is used in the ambulance role. The FAR provide a series of measurements that must be made regarding the noise level at numerous positions around the aircraft and its path. The entirety of these requirements are found in Appendix H to Part 36 under the FAR [29]. The conditions for the test must be standardized according to pressure, temperature, humidity, wind speed, and a standardized zero-obstruction line of sight test path. The flight profile, including the takeoff, flyover, and approach paths, all must follow the reference conditions or be corrected to them as in figures H1 through H3. The noise levels are then recorded in effective perceived noise decibels (EPNdB) from reference points at A, $S_{starboard}$, and S_{port} in all 3 figures [29]. The Appendix provides a series of equations used to calculate the EPNdB, which is used to determine whether the helicopter is a stage 1 or stage 2 aircraft. Stage 1 aircraft are older aircraft that do not meet the stage 2 aircraft requirements, while stage 2 aircraft noise limits are listed as:

> (i) *For takeoff calculated noise levels* —109 EPNdB for maximum takeoff weights of 176,370 pounds (80,000 kg) or more, reduced by 3.01 EPNdB per halving of the weight down to 89 EPNdB, after which the limit is constant.
>
> (ii) *For flyover calculated noise levels* —108 EPNdB for maximum weights of 176,370 pounds (80,000 kg) or more, reduced by 3.01 EPNdB per halving of the weight down to 88 EPNdB, after which the limit is constant.
>
> (iii) *For approach calculated noise levels* —110 EPNdB for maximum weights of 176,370 pounds (80,000 kg) or more, reduced by 3.01 EPNdB per halving of the weight down to 90 EPNdB, after which the limit is constant [29].

All new aircraft are required to meet the stage 2 aircraft requirements.

105 CMR 170.000 defines the requirements for operating an ambulance in the state of Massachusetts by regulating the EMS system statewide. [1] In these regulations, 2 levels of ambulance care are defined, Basic Life Support (BLS) Advanced Life Support (ALS), and a critical care service level. Class IV ambulances are licensed to provide paramedic level ALS and as such require a correspondingly trained crew. [1] Paramedic level ALS is the second highest level of care that an ambulance can be licensed for. An aerial ambulance therefore must be able to provide care at the BLS, ALS-Intermediate, and ALS-Paramedic level.

The different levels of care are differentiated by the procedures that the EMTs are required to do when providing care to patients under specific circumstances. These procedures are taught to students during the training for the different levels of EMTs and explained by the Office of Emergency Medical Services in the Emergency Medical Services Pre-Hospital Treatment Protocols. The document provides a number of situations and the corresponding procedures for each level of care in a step-by-step basis. If a certain situation requires care above a certain level, it does not include a list of procedures for those surpassed levels [32]. Therefore, an understanding of these procedures is necessary for not only the ambulance EMTs but also for the dispatcher so that the appropriate level of ambulance is dispatched. These protocols apply to all ambulances by their class, including the class IV aerial ambulance.

Each class of ambulance has a staffing requirement according to its service level. As a paramedic level service vehicle, a class IV ambulance must be staffed according to 105 CMR 170.305. This regulation states:

> When a Class IV ambulance transports a patient being provided advanced life support services, the ambulance must be staffed with at least two EMTs and one pilot. One EMT must be a registered nurse certified, at a minimum, as an EMT-Basic. The second EMT shall, at a minimum, be a certified EMT-Paramedic. Both EMTs shall have additional training in the emergency care services to be used on the aircraft. However, in cases where there exist special patient needs, such as during an inter-hospital intensive care transport, another registered nurse, a physician's assistant or a physician may be substituted in place of the EMT-Paramedic. [1]

In a standard ambulance situation, both EMTs will have adequate training to provide care for the patient solely from their EMT training. Additional training is required in situations such as sea-based recovery, mountain recovery, in cases where the patient requires advanced care, and other extreme conditions.

The Office of Emergency Medical Services outlines the required equipment that an ambulance must carry based on its class in the Administrative Requirements Manual. These requirements are set as to make it possible for the crew to provide a level of care required by the service level of the ambulance. The particular equipment requirements are outlined in Appendix A [62].

Ambulance service providers are required to have a plan for a backup ambulance should the initial ambulance be unable to complete the mission. Each ambulance must have at least two backup vehicles, notated as the first and second backup vehicles. For a class IV ambulance, the first backup vehicle must be either another class IV or a class I or II. The second backup vehicle can be either a class IV, a class I or II, or a class V ambulance. These backup vehicles must be capable of providing a service equal to or greater than the vehicle being backed up [1].

It is evident that the behaviors of EMTs are governed by the regulations set to provide a standard of care. These standards guarantee a minimum level of care, but many caregivers will exceed the minimum level of care through actions such as better equipping their helicopters making personal connections with patients. The regulations therefore govern, but do not define the procedures of EMTs.

Section 2.1.3 Costs

Helicopter costs are the most inhibitive factor when deciding whether to obtain or use a helicopter for ambulance purposes. The other factor that contends with costs is the availability of an infrastructure in place for the helicopter to take off and land across the entire zone of operation for a helicopter. This is not as universal as cost however, as some areas have more landing zones than others, but all flights cost significantly more than their ground based alternatives. Thus it is important that the costs associated in helicopter transport are understood so that they can be reduced.

Firstly, an overall sense of the costs of maintaining an aerial ambulance must be established. Air Methods, the company that leases aircraft to both UMass Memorial LifeFlight and Boston MedFlight provides a total operating cost for its 434 aircraft nationwide, providing a means to average out the cost of operating a helicopter for a medical purpose. The only problem with this approach is that the aircraft we are interested in, the EC135 and EC145, which are relatively small craft, and the S-76C++, which is a larger aircraft, are all averaged in with larger aircraft, which produce larger operating costs. Thus, this means provides an estimate, which is above the likely operating cost and as such is a safe measure to use. The averaged out cost comes to ~$1.11 million dollars in operating expenses annually [5]. This is on top of the initial costs of purchasing an aircraft, or the price to lease it from another company such as Air Methods. The costs associated with purchasing the three helicopters of interest are:

Table 3 - Common HEMS Helicopters and Costs I

EC135	$3.9 million [12]
EC145	$5.5 million [12]
S-76C++	$7.9 million [13]

The ongoing costs for both Boston MedFlight and UMass Memorial LifeFlight in regards to the aerial ambulance consist of operating costs and the cost for leasing the aircraft. To better understand what contributes to maintenance cost we break it down into its components and analyze what contributes to each component. The relative weights in comparison to each other are relevant in understanding which components should be examined in depth. Ward Hiesterman, Assistant Manager of the Gallatin Rappel Crew provides a breakdown of the costs per flight and the fixed costs associated with maintaining a helicopter [44]:

Table 4 - Aviation Operations Cost Worksheet

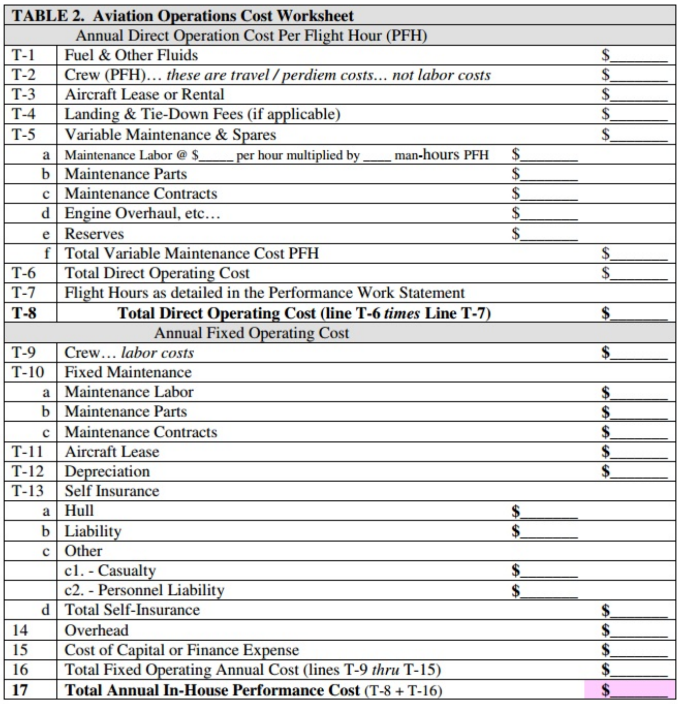


TABLE 2. Aviation Operations Cost Worksheet			
	Annual Direct Operation Cost Per Flight Hour (PFH)		
T-1	Fuel & Other Fluids		$_______
T-2	Crew (PFH)… *these are travel / perdiem costs… not labor costs*		$_______
T-3	Aircraft Lease or Rental		$_______
T-4	Landing & Tie-Down Fees (if applicable)		$_______
T-5	Variable Maintenance & Spares		$_______
a	Maintenance Labor @ $_____ per hour multiplied by ____ man-hours PFH	$_______	
b	Maintenance Parts	$_______	
c	Maintenance Contracts	$_______	
d	Engine Overhaul, etc…	$_______	
e	Reserves	$_______	
f	Total Variable Maintenance Cost PFH		$_______
T-6	Total Direct Operating Cost		$_______
T-7	Flight Hours as detailed in the Performance Work Statement		
T-8	**Total Direct Operating Cost (line T-6 *times* Line T-7)**		**$_______**
	Annual Fixed Operating Cost		
T-9	Crew… *labor costs*		**$_______**
T-10	Fixed Maintenance		
a	Maintenance Labor		**$_______**
b	Maintenance Parts		**$_______**
c	Maintenance Contracts		**$_______**
T-11	Aircraft Lease		**$_______**
T-12	Depreciation		**$_______**
T-13	Self Insurance		
a	Hull	**$_______**	
b	Liability	**$_______**	
c	Other		
	c1. - Casualty	**$_______**	
	c2. - Personnel Liability	**$_______**	
d	Total Self-Insurance		**$_______**
14	Overhead		**$_______**
15	Cost of Capital or Finance Expense		**$_______**
16	Total Fixed Operating Annual Cost (lines T-9 *thru* T-15)		**$_______**
17	**Total Annual In-House Performance Cost** (T-8 + T-16)		**$_______**

The table breaks the continuing costs into two distinct categories: direct operation cost per flight hour and fixed operating costs. Direct operating costs per flight hour are costs associated with the active use of the aircraft, which aren't gained when the aircraft is not in use. Fixed operating costs are those costs that are unavoidable by the operator of a helicopter, such as required yearly maintenance and the salaries for the crews. Both areas are directly connected to the helicopter being used and the assignment of the helicopter. It's possible to break the costs down and explore them in the context of an aerial ambulance.

The direct operating costs for aerial ambulances are a large portion of the operating costs due to the amount that the helicopter is used. Boston MedFlight provides care to more than 2700 patients per year with their 3 helicopters [27], averaging between 2 and 3 flights per helicopter per day. Based on the fast cruise speed and the range of the EC135, EC145 and S-76C++, the assumption that every flight is at the maximum range of the helicopter, and a mix of the helicopters, each flight on average has a duration of 2.6 hours. [27][26][70] Therefore each helicopter has an average flight time between 5.2 hours and 7.8 hours a day. These assumptions are extremes, and are beyond what the helicopters will actually experience, but when budgeting money for the operation, it's a safe model to use.

Fuel costs for aircraft are going up due to the rising price of oil. By averaging the range and flight time for the 3 helicopters used as aerial ambulances, it's found that the helicopters average between 1.68 miles per gallon of jet fuel used for the S-76C++ to 2.13 miles per gallon of jet fuel used for small helicopters such as the EC135 [27]. Real fuel usages will be lower than a gallon per mile due to usage while on the ground and the possibility of inefficient flight speeds. Averaging the maximum ranges [27][26][70] that the helicopters can fly using the same assumptions as before, operators can expect an average maximum of 1192 miles flown per day.

Based on the price of fuel at the General Edward Lawrence Logan International Airport in Boston where jet fuel is at most \$8.78 per gallon and the average maximum flown miles per day previously calculated, \$4900 must be devoted to fuel per day for the EC135 and \$6200 per day for the S-76C++. This translates to monthly expenditures of \$147000 for the EC135 to \$186000 for the S-76C++. Fuel prices are therefore a large expenditure that is difficult to reduce without changing to a more fuel-efficient helicopter or fueling from a different location.

Crew costs are a function of the number of crews that an operation employs. In order to operate a class IV ambulance, the hospital must hire additional EMTs and pilots to cover the increase in positions. Due to the nature of the service, a full roster to cover all hours of the day without any gaps in coverage is required, varying based on the shift lengths and number of time off. This means that at least 3 teams of EMTs and pilots must be hired to account for vacation time and days off, putting a further financial burden on the hospital. A full 4 teams would be able to sufficiently meet the needs of a single helicopter. A team for an aerial helicopter consists of at least one EMT-Paramedic and one EMT-Basic that is trained as a registered nurse [1]. Some hospitals may decide that they require more based on demand, however. Due to the high level of training of the crew, it's safest to estimate the salaries of the crew as the average of the top third of the EMT salaries. This puts each crewmember's earnings as an averaged \$51000 annually [34]. The crew total comes to at \$153000 annually, or \$12750 per month. This is variable on a per crew basis, and one of the easiest variables to control.

Both Boston MedFlight and UMass Memorial LifeFlight use aircraft provided to them by Air Methods. Air Methods leases some of its helicopters and owns the other portion. To understand the costs associated with owning a helicopter, we assume that Air Methods charges a leasing fee in the form of a capital lease that translates to a purchase after 5 years, amounting to

90% of the current market value. The following table provides the current market value, the translated cost to the company, and the per month payments for the 3 popular aerial ambulances [35].

Table 5 - Commons HEMS Helicopters and Costs II

	EC135	EC145	S-76C++
Market Value	$4.2 million	$5.5 million	$7.9 million
90% Capital Lease Price	$3.78 million	$4.95 million	$7.11 million
Per month installments	$63000	$82500	$118500

These prices will be ongoing, beyond the 5-year period that results in Air Methods fully purchasing the aircraft. These assumptions may differ on a per craft basis, as the time period, percentage of market value price may change, or the contract may be for an operating lease, which is on a per case basis.

Maintenance is a cost that has many facets to it. Maintenance requires a specialized crew to work on the aircraft, replacement parts to replace faulty ones, as well as preventative inspections to make sure operation is smooth. There are two types of maintenance, the maintenance that's required based on the number of hours flown, and maintenance that is required due to the age of the aircraft due to effects such as oxidation and deterioration. UMass Memorial LifeFlight has 2 mechanics for its single aircraft [79], thus an 2 mechanics per aircraft is a safe assumption. Assuming the pay of the two mechanics averages out to the mean helicopter mechanic salary of $94000, the hospital may expect to pay $188000 for maintenance workers per craft. To determine the remaining portion of the maintenance cost, averaging Air Methods' maintenance cost for 2011 across its fleet of 434 craft provides a maintenance estimate on a per helicopter basis of $205000 [5]. Summed together, the total maintenance cost comes to $393000 annually.

Due to the high risk associated with operating a helicopter, companies choose to insure their expenditures. Helicopter insurance is issued on a per case basis, with consideration to the pilot, the age and type of helicopter, the location, and the proposed use of the aircraft. All of these factors combine into a risk assessment that the insurance company must make in order to provide a quote for the company operating the helicopter. As the risk and the potential need to pay out for a damaged helicopter rises, so does the quote price. In order to provide an estimate, we assume an annual rate of 1.5% of the market value and assume new helicopters of each of the three types used.

Table 6 - Commons HEMS Helicopters and Costs III

	EC135	EC145	S-76C++
Market Value	$4.2 million	$5.5 million	$7.9 million
Monthly Rate	$10500	$13750	$19750

These are estimates with a large degree of error. Insurance companies may choose to charge more due to the high number of flight hours that aerial ambulances accrue, the stressful nature of the job and its effect on the pilot, and the possibility of not pre-approved landing sites. All of these effects increase the risk of an accident and as such will affect the quote price. This is for the base insurance on the helicopter itself, additional coverage would result in additional costs.

Overhead costs comprise of the remaining costs that have not yet been accounted for. These include items such as rent, medical supplies, and unforeseen expenses. If the helicopter is based at a hospital or an owned base, the rent cost is eliminated. Due to the unpredictable nature of the consumption of medical supplies and low cost relative to the rest of the upkeep, the costs associated with maintaining medical equipment are neglected. Likewise for unforeseen expenses, it's impossible to account for them beforehand. These expenses must be accounted for, however, and as such a reasonable monetary buffer amount should be allocated by the hospital. Overall, overhead is unpredictable and likely small in comparison to the rest of the expenses, thus as a whole it is neglected.

The sum of the projected costs produces the annual budget requirement in order to operate an aerial ambulance. By estimating using the S-76C++ costs, the total comes to be $2.173 million annually under the assumptions that have been made. This is the total for just one helicopter, and can vary based on factors that have been mentioned in the respective breakdowns. Therefore, operation and maintenance of a class IV ambulance is a very expensive procedure.

To gain context to the burden that this would place upon a smaller hospital, we examine Berkshire Health Systems in Western Massachusetts. According to their annual report for the year of 2011, the company as a whole, which spans multiple operations (2 hospitals and a number of smaller clinics and other services), claimed a net gain of roughly $6.4 million dollars [14]. In order to obtain a helicopter, necessary supplies, crew, and benefits this gain would be entirely negated, making growth in other fields impossible and slowing future growth significantly due to increased and ongoing expenses. As this example demonstrates, due to the excessive costs associated with operating an aerial ambulance, many hospitals are unable to afford expanding their ambulance services beyond class I, II, or IV.

The expenses associated with operating a class IV ambulance can be recovered through the use of the ambulance to recover patients. Under the assumption that the ambulance will be used constantly, the ambulance will be able to cover the expenses with revenue from patient care. However, the opposite situation is also possible: due to the high cost placed upon the patient, use of the aerial ambulance cannot be justified as opposed to cheaper ground methods. Thankfully, this latter case is not the case due to insurance being able to cover the costs of class IV ambulance use if it is deemed necessary. Due to a mix of incomplete health insurance coverage of the population and companies refusing to completely cover aerial ambulance expenses, there exists a middle ground between the two extremes of use and non-use that hospitals experience.

The costs of operating and maintaining a helicopter make it difficult for many hospitals to justify acquisition of one. Cost is not the only factor in determining whether to operate a helicopter. Factors such as infrastructure, population density, and other extreme conditions weigh towards whether the expenditure is worth the opportunity cost compared to other growth methods.

Section 2.2 Transport

Section 2.2.1 Procedures and Regulations

Prior to the arrival of an aerial ambulance, a landing zone coordinator needs to ready the site. The Landing Zone Coordinator, the emergency responder with knowledge of helicopter operations, must remain in constant communication with the pilot. When choosing the location of the landing zone, one must take into account the physical features of the environment around them.

The objective is to get the landing zone as close to the accident site as possible, while avoiding environmental hazards. Environmental hazards that need to be taken into account are overhead hazards. Overhead hazards include tree limbs, towers, and electrical lines. The standard dimensions for a landing zone depends on the visibility and time of day. During the daytime, a landing zone should be at least 75’ by 75’ square area. Under nighttime and low visibility conditions, such as dense fog, the landing zone should be expanded to 100’ by 100’ square landing area [5]. The ideal landing zones are parking lots, sports fields, roads, and other firm surface locations. The area should be cleared of all debris and to prevent dust and gravel from flying up when the helicopter lands, dry areas should be wet down by EMTs on the scene. The landing zone should be as close to the accident as possible to prevent unnecessary vehicle transport of the patient.

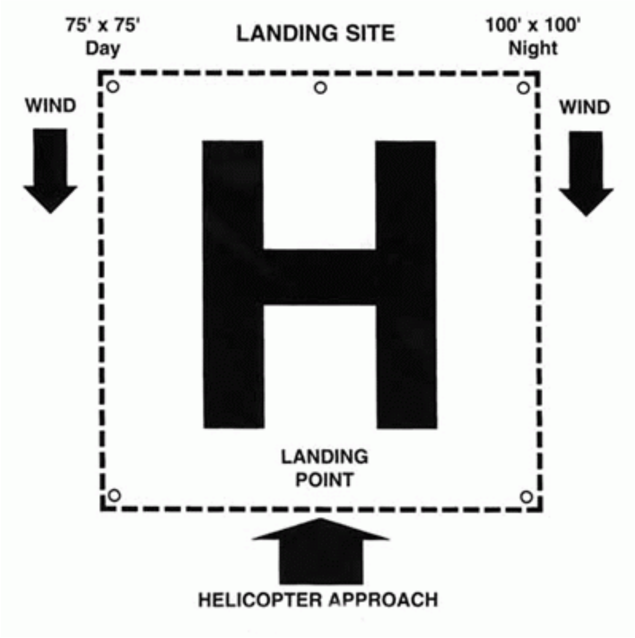
Four lights in the corners of the site should mark off the area designated as the landing zone. A fifth light is sometimes also requested in order to inform the pilot of the direction of wind. Strobe and rotating emergency lights are useful to a pilot when trying to locate a landing site but should be minimized or extinguished during takeoff and landing. It is best to communicate, if able, with the pilot in order to determine the best method in which to illuminate a landing zone. Table 7 shows acceptable and unacceptable ways to mark a landing zone.

Table 7 - Landing Site Markers

Acceptable Markers to Use	Unacceptable Markers to Use
Small weighted cones (day time)	Open flames or hot coals
Chem-lights at night secured to the ground	Police barricades or plastic cones
Flares secured to the ground	Markers that can be blown away by chopper
Auxiliary lighting pointed to the ground	Multiple rotating flashing lights on a vehicle
	Flashlights/spotlights aimed at the helicopter

While flares are an acceptable marker to use, discretion is required due to potential hazards such as starting a brush fire or causing disorientation for the pilot. Emergency vehicles can also be used to mark the corners of the landing zone, but all other automobiles and non-essential personnel must be cleared 200’ from the landing area. Below depicts a picture of the standard landing zone. The circles indicate lights marking the edges of the landing zone and wind direction.

Figure 1 - Sample Landing Site



At night it is important to switch off all unnecessary light around the landing zone. With the improved night vision it will allow for the pilot to distinguish landmarks and potential hazards around the landing zone. All lights being used during a night mission should be pointed toward the ground and be tinted red or blue because white lights will disrupt a pilots' night vision.

It is also important to communicate with the pilot about any potential hazards. Power lines are a very common hazard at most landing sites because they are difficult to spot even in broad daylight and can be virtually invisible to a pilot at night. In order to assist the pilot, ground crews can mark the location of electrical wires with a line of flares spaced 20 feet apart between the landing zone and the hazard- closest to the hazard [5].

Another potential hazard at landing sites can be the wind. It is essential inform the pilot the direction of the wind in relation to the approach and departure paths. The wind, both natural and created by the helicopter, is also the reason to have a clean landing site; otherwise something could very easily be swept up into the blade or engine areas of the helicopter and could create a potential accident.

Spectators and pedestrians can also become a potential hazard at the accident site. They can create a disruption in the flow of traffic and unforeseen problems at the landing site. It is important that all non-emergency personnel remain 200' away from the landing site and all emergency responders' 100' back form the touchdown site. Emergency workers should wear eye protection and secure all hats by fastening the chinstraps [48].

While the landing zone is be prepped for the helicopters arrival, the landing zone coordinator should be the only one to communicate with the helicopter and remain in constant contact with the HEMS pilot. The landing zone coordinator relays the following information:

- The duties of the HEMS crew (search, rescue, transport).
- The location of the landing zone in relation of the accident.
- The size of the landing zone, how it is marked, any nearby obstructions, and the direction of the wind speed.

If the helicopter is there to transport a patient the following information must be included:

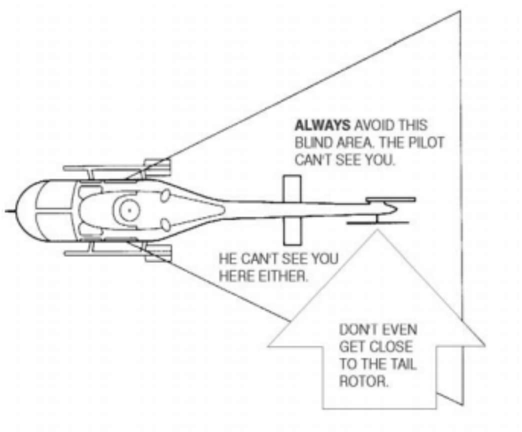
- The number of patients that will be transported.
- The age of the patient (adult or pediatric), and the injuries the patient has sustained.
- Whether or not the patient has been extracted from the accident scene of is still entrapped [5].

The constant communication between the ground crews and the pilot allows for the crew of the aerial ambulance to be prepared of the conditions they will be landing in, as well as what their duties will be once they arrive.

The landing zone coordinator should station themselves in the middle of the outer perimeter, with their back to the wind. This allows for the helicopter to approach and land into the wind, which is preferable for most pilots. Due to the pilots' inability to see behind him, the most critical task for the landing zone coordinator is to watch the tail rotor during landing. It is the landing zone coordinators duty to assist the pilot in landing through a series of hand signals, the most important two being when to land and when to abort. If the landing zone is ready and there are no potential hazards the landing zone coordinator will outstretch both hands and point to the area that indicates the landing zone. To abort the landing, the coordinator performs a crossing and uncrossing motion overhead to wave off the pilot. Other hand gestures can be used to assist the pilot in landing, but the decision of where to put the helicopter down ultimately rests with the pilot himself.

After the helicopter has been safely guided to the ground, no one is allowed to approach the chopper. The pilot will indicate when the rotor blade has slowed enough to allow personnel to approach. Those who do move toward the helicopter must not only receive the pilots' permission to approach but also stay within the pilots' limited peripheral view (shown in Figure 2).

Figure 2 - Safe and Unsafe Areas Around a Helicopter Blade



Due to possible wind gust that have the potential to cause the rotor blades to dip to human height, all those approaching the chopper must remain in a crouched position and be sure to carry nothing overhead. Other concerns include:

- When on uneven terrain, never approach from the uphill side.
- Always walk to and from the helicopter.

- No hat can be worn near the helicopter and all helmets must be strapped on with a chinstrap.
- Always avoid walking near the tail rotor.

The crew of the helicopter will disembark when it is safe to do so. At that time any new information regarding the patient is to be relayed from one person to the crew. Some crews may ask for some assistance to load the patient, those who are chosen to assist must follow the crew's instructions and exit the same way the approach the helicopter. Once the landing zone is clear of all emergency personnel, the landing zone coordinator will then notify the pilot to take off. Emergency services on the ground should keep the landing zone secured for at least five minutes after takeoff. This will allow the pilot to return to the landing area if an emergency develops shortly after departure.

Section 2.2.2 Hospital Affiliation

The HEMS of Massachusetts is currently affiliated with only two hospitals: UMASS Memorial in Boston, and UMASS Memorial in Worcester.

Figure 3 - HEMS Operations in Massachusetts

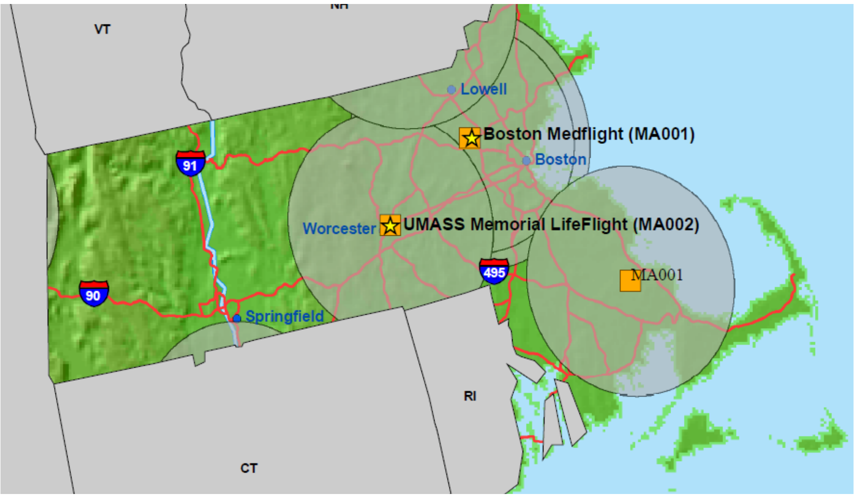


Figure 3 shows the three designated landing areas in Massachusetts [53]. The circles indicate a twenty-minute radius from the landing area. The two with stars specify that the location is at a hospital, while the other is a landing base. A landing base is a designated area of land that is a flat hard surface, without any environmental hazards around.

As you can see from the picture that the eastern side of the state is all mostly within a twenty minute flight of a landing zone, however Cape Cod and the western half of Massachusetts are roughly forty minutes away from an HEMS landing base. This means that there is no guarantee to find a viable landing option and it will take that much longer for the helicopter to reach you.

HEMS currently allows for more than 80 million Americans to receive care at a Level 1 or 2 trauma center in one hour, that they may not be able to reach otherwise.

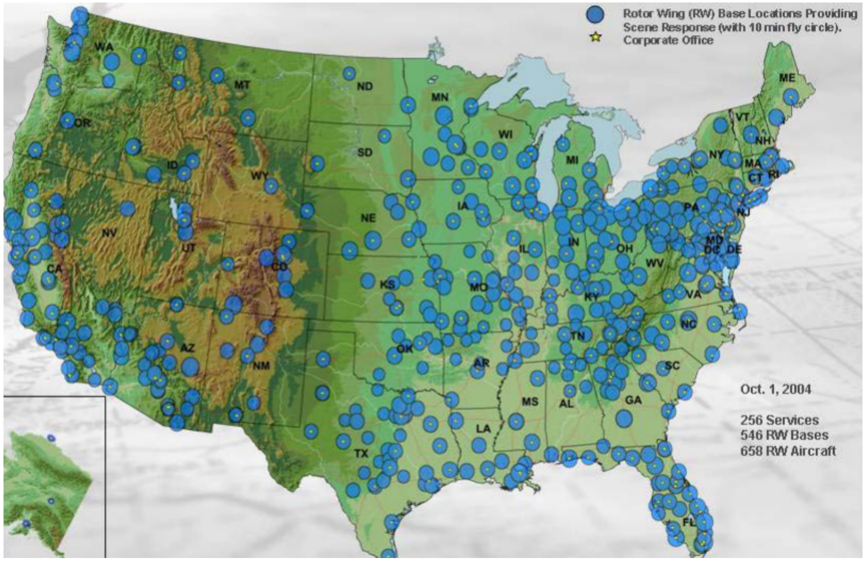
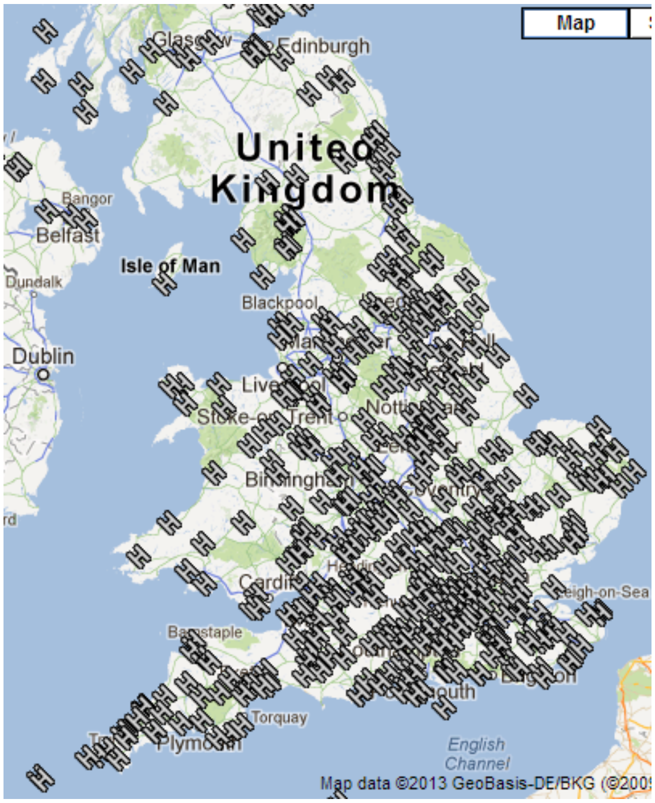


Figure 4 - US HEMS Operations as of October 1, 2004.

The map above shows the number of aerial ambulance locations and their 10-minute fly radius in the United States [53]. As you can see in the more heavily populated areas of the country, the northeast, Florida, Texas and California, have overlapping access HEMS sites. However, some states such as Maine, Wyoming, South Dakota, and Nevada, have very limited access to the HEMS services. It is important that were distribute more landing and traveling locations for helicopters in the more rural areas because those are the people who are not within one hour of a trauma center and could benefit from the quicker mode of transportation.

However this map also shows the limited number of designated landing zones in the country. At the middle of each of those circles is the one designated landing zone for that ten-minute radius. Just like in Massachusetts, many of those landing sites occur at hospitals. If we compare the United States HEMS landing site distribution to another country, such as the United Kingdom (pictured below), you would see the United Kingdom has a greater saturation of designated landing zones than the United States.

Figure 5 - HEMS Bases in the United Kingdom



An "H" represents where a helicopter can safely land based off of the landing zone criteria earlier mentioned. As you can see the country is saturated with safe potential landing areas for helicopters. This allows for the vast majority of the country to have access to the potential life-saving transportation that HEMS has to offer.

One of the goals discussed later will be how to increase the number of landing sites for the United States in order to achieve a similar abundance of safe landing sites, helping increase the number of patients that have access to HEMS.

Section 2.2.3 Transport Time

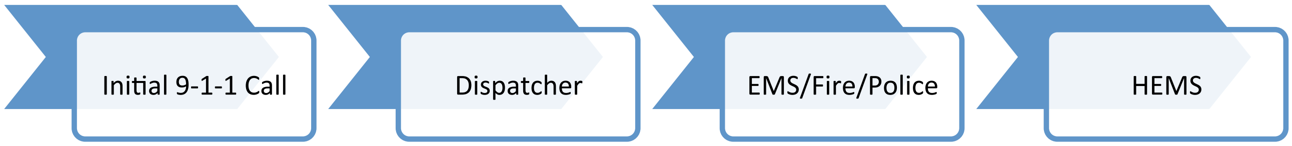
Helicopters provide millions of Americans access to Level 1 and 2 trauma centers in an hour, which could not otherwise do so. HEMS is called to an accident scene for mainly when a patient is critical condition and needs to be either transferred to a critical care center farther away or quicker than an ambulance could.

A time critical patient is one with a life threatening injury such as problems involving breathing or circulation. It is important that first responders are notified or identify the problem, as it is critical to the extraction process. first responders arrive on scene they assess patients with the five step acronym MARCH- massive haemorrhage control, airway with cervical spine control, respiration, circulation, head injury [35]. It is important that the patient is assessed in that order because massive haemorraging or a blocked airway can quickly kill a patient.

The first responder’s job is to stabilize the patient as much as possible at the site of the accident and prepare for the patients to be transported to the hospital. However, in some cases the first responder’s job also includes informing dispatch to send a helicopter. It is important to notify HEMS as soon as possible because every minute counts. The median time it takes for a helicopter to arrive on scene in a rural area is 30 minutes. This includes the time it takes before the chopper is called to the scene [60]. It takes on average 9.2 minutes before the call is made for the helicopter to dispatch scene of an accident.

When HEMS is called onto the scene it is not always with the initial 9-1-1 call. When a person initially contacts dispatch to alert them of an accident, they tell the dispatcher the nature of the emergency. It is highly unlikely that the person calling 9-1-1 know the exact extent of the injuries at an accident scene and can tell the dispatcher that HEMS is needed. There are two different processes for calling HEMS to a scene. The first, depicted below, has HEMS being sent out right away.

The initial 9-1-1 caller has provided the dispatcher with enough information to send out HEMS. The second method is as follows:



The second method is the most common, in which after the initial wave of first responders assess the situation, they then call for HEMS to be sent out. The second method also creates a longer wait time for the patient who is in critical care.

Landing bases can be essential in order to cut back on transport time because it is a designated area of land that does not need to be prepped as a landing zone. If a patient is well enough to be transported by ambulance to a landing base, then the helicopter and ambulance can essentially meet in the middle and transfer the patient. This can help save precious minutes for the patient.

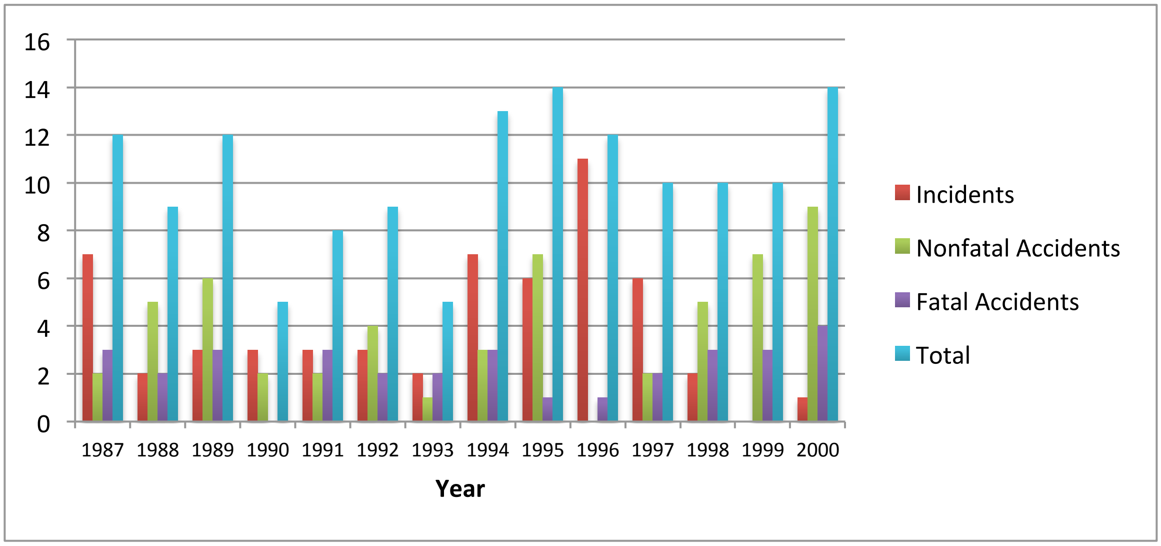
Landing zone regulations and locations can help increase the overall success rate of the operations and duties HEMS crews must complete. If the landing zone is unsafe or unsecured, it could lead to many unnecessary and avoidable accidents. The purpose of HEMS is to help save lives, by using a method of transportation quicker than a ground emergency vehicle, however that can sometimes lead to unforeseen incidents.

Section 2.3 Accidents and Incidents

Section 2.3.1 Human Error as a Major Consideration

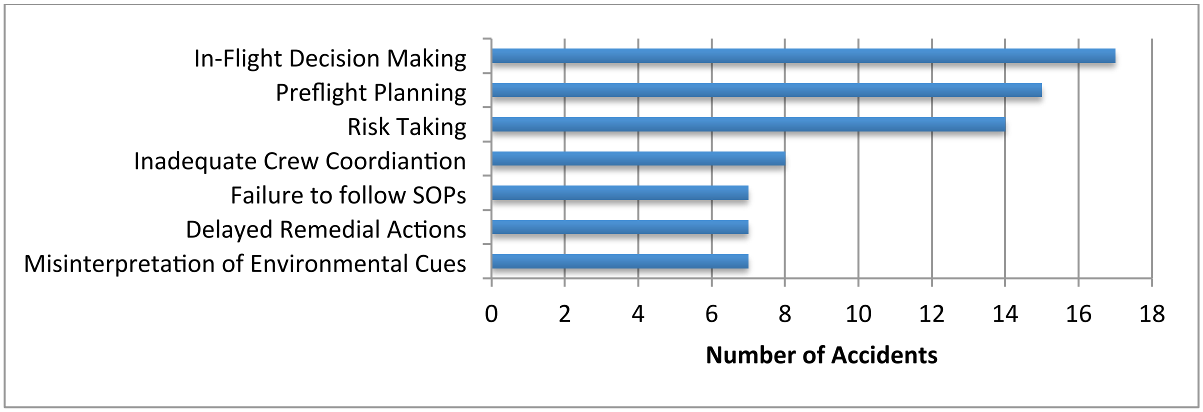
Rarely is a HEMS accident caused by a single event. In the vast majority of cases, it is a multitude of events that cause an incident or accident to occur. As the industry deals with human interactions in a tight time frame and a high stress environment, it comes as no surprise that human error factors play a major role in incidents and accidents. HEMS operations take place at all hours, in all weather conditions with extreme urgency for the livelihood of the patient on board. This often results in a hectic work atmosphere, with tangled communications, and a multitude of distractions. The summation of the many difficulties can cause unneeded pressures on the pilot and EMS crew leading to accidents and incidents and possible fatalities.

Figure 6 – US HEMS Accidents and Incidents 1987 – 2000 [Blumen]



With 87 accidents and 56 incidents occurring from 1987 to 2000 in the United States (See Figure 6), a study by Patrick R Veillette, Ph.D. found that human error came in to play in 76 percent of the time, with a detailed breakdown below in Figure 7. Of the accidents, human error was associated with 76 percent of the accidents and a whopping 84 percent of the fatal accidents, [16]. Of the 275 patients, EMS crew, and pilots onboard the helicopters, there were 96 fatalities, 33 serious injuries, and 31 minor injuries. 36 of the 87 aircraft were destroyed with the remaining 51 suffering substantial damage [81].

Figure 7 - Human Error Factors in HEMS Accidents 1987 - 2000 [Blumen]



While incidents and accidents occur due to pilot error, there are often unneeded stresses pressuring pilots into making the poor decisions that lead to crashes. Often cited as a primary pressure is the heavy workload put upon HEMS operators. All flight duties are usually tasked to a single pilot with no copilot, and often no autopilot. This requires the pilot to perform a large number of tasks in a small time frame. Multitasking to provide aircraft control, navigation, and monitoring radio frequencies is a daunting task for a single pilot and after extended periods of time, it can take its toll. Monitoring multiple radio frequencies in particular can be difficult, as the pilot must stay in contact with the destination hospital, EMS crew in the cabin, EMS crew on the ground, and air traffic control. The increased workload can lead to lapses in judgment, inability to recognize errors, lack of concentration, forgetfulness, and fatigue [18].

General confusion also comes into play with a single pilot's inability to accurately process the large amounts of data and communications. In Veillette's study, fourteen pilots reported confusion in understanding of navigational equipment that conflicted with other information. The inaccurate navigational equipment also factored in in cases where aeronautical charts were missing information that would have aided a pilot in maintaining positional awareness [81].

One such instance where an additional pilot could have adverted an accident occurred on February 12, 1999 in Toledo, Ohio. The patient had already been picked up and the Aerospatiale AS 355 was in approach to the hospital. It was night, and the pilot had been informed that snow was reducing visibility on the landing pad. With such adverse weather conditions, the attempted approach involved climbing and then executing a very-high-frequency omnidirectional radio approach. The pilot was unable to attempt this approach however as he had no copilot and only a basic instrument package. A descent was initiated into an open area and the pilot encountered instrument meteorological conditions [IMC] – conditions in which a pilot is forced to fly primarily with references from instrument readings due to inability to use visual cues. The helicopter struck a tree and continued to descend coming to rest in a house. This accident resulted in three serious injuries and substantial helicopter damage. Had the pilot had a copilot, a VOR approach could have been attempted possibly avoiding injury and damage [81].

In addition to heavy workload, time pressures are a frequent contributor to accidents and incidents. These pressures are divided into three categories: patient condition, rapid mission preparation, and low fuel. Various time pressures forced a rushed crew at various stages of operation. This lead to oversights such as inaccurate preflight planning, incomplete preflight checklists and inspections, failure to acquire enough fuel, and flying before required maintenance. Reported 44% of the time, a patient in critical condition was found to effect pilots the most [16]. While the vast majority of programs strive to isolate pilot decisions from patient condition, pilots often find themselves aware of the state of the patient through nonverbal signs from the EMS crewmembers. In some instances, a patient's condition can force a precautionary landing to prevent further deterioration of patient health. In a 1997 survey of HEMS pilots, it was found that seven percent of pilots had conducted a precautionary landing due to a change in patient condition [81].

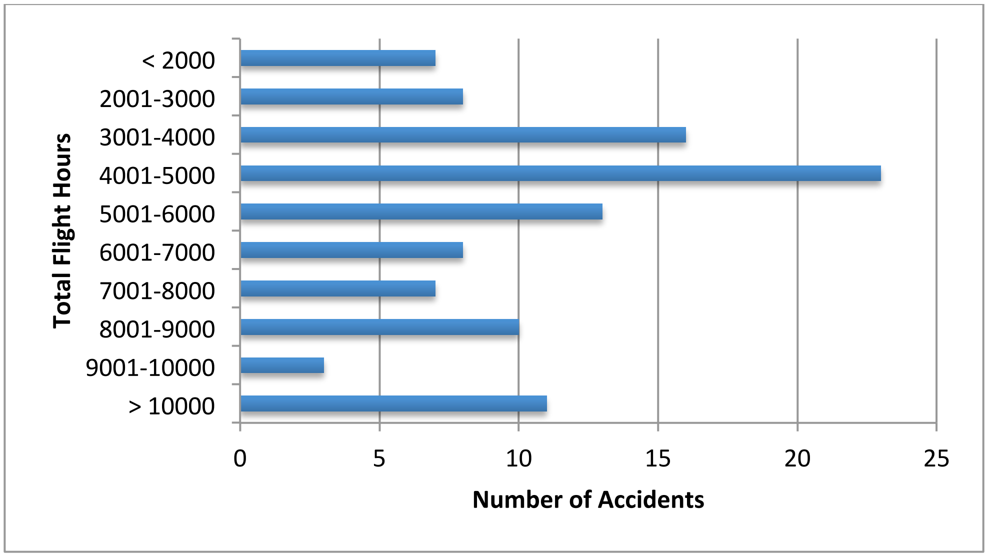
Contributing in 15 accidents, rapid flight preparation was the next most cited time pressure [81]. Especially present in the most serious needs of HEMS services, a helicopter that needs to get off the ground fast may find hurrying through pre-flight operations problematic. Without adequate pre-flight preparation, accidents can occur during takeoff. Improper pre-flight procedures caused an emergency water landing in February of 1991 in Valdez, Alaska. 30 minutes into flight one engine lost power and the pilot was forced to descend. It was later found that the pilot had failed to turn on the four fuel pumps before take off. Other, less severe, accidents have occurred including relatively simplistic ones such as failing to remove the auxiliary power cord prior to takeoff. This causes a drastic yaw before the power cord is ripped loose, and forces an early landing in some cases [81].

Another factor that can lead to poor pilot decision-making is difficulty in communications. Issues most often arose between pilots and air traffic control [ATC] and FAA flight service stations [FSSs]. Inability to communicate properly with ATC can lead to misunderstanding of clearance requirements. If said clearance requirements are not properly met, mid air collisions can occur resulting in multiple damaged or destroyed helicopters [18].

Communication can also become difficult with the levels of noise than are present in the cockpit of a helicopter. Sounds produced by medical equipment, the helicopters rotors, and EMS crewmembers can easily overpower important broadcasts from ATC and FSSs. FSSs provide information regarding important changes in weather conditions and if these details are missed accidents can occur. Changes in meteorological conditions led to one such accident in November of 1989. A pilot of a Bell 206L III encountered strong-than-expected head winds and was running low on fuel. The engines lost power as the fuel ran out, and the pilot conducted an emergency landing. The pilot and two passengers were unharmed, but the aircraft suffered substantial damage [81].

Distractions came into play in many incidents and accidents studied by Veillette. Such distractions included aircraft equipment problems, monitoring of multiple radio frequencies, traffic avoidance above landing and take off zones, and basic interruptions. Also present were radio congestions, noise from medical equipment, activity from EMS crew or the patient, and changes in fuel, altitude, or aircraft orientation. Distractions do not all come from inside the helicopter however. Veillette pointed out that internal factors could play a role as well including personal or family related concerns, anxiety, involvement in patient condition, and general inattention [81].

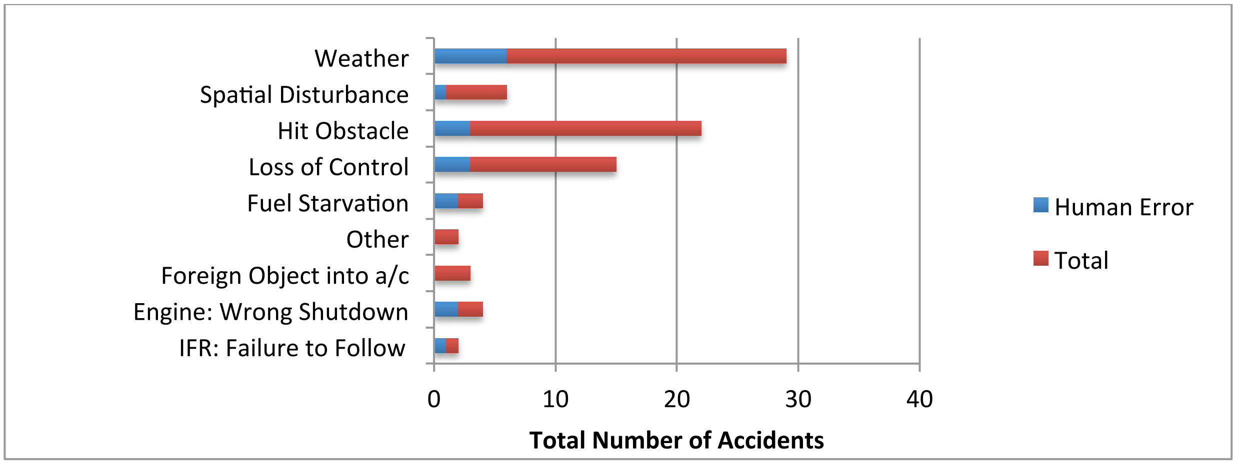
Figure 8 - Total Flight Hours vs. Number of Accidents [Blumen]



An accident occurred in Caro, Michigan on February 1,1994 as a direct result of a distraction. A helicopter was inbound to a newly designed landing zone, and was flying in snowy conditions. The pilot established a hover position about 10 feet above ground level to assess the landing site. The downward thrust of the rotor blades blew snow up partially obscuring the pilot’s vision. A paramedic crewmember grabbed the pilot’s arm warning him to watch out for a light pole. Distracted, the helicopter struck light assembly damaging the rotor blades [81].

There is also a slight connection with pilot experience and number of accidents, as shown above in Figure 8. While not a guarantee, generally pilots with more hours in flight are less likely to take part in an accident. Figure 3 shows the general breakdown of flight hours versus accidents. However, this figure does not show more important flight hour statistics such as hours in a specific make or model of an aircraft. Of the involved pilots for the above data, 27 of the 122 accidents involved a pilot with less than 200 hours of flight time in the made or model of the helicopter they were piloting. 18 of the accidents had fewer than 100 hours and one pilot had only three hours of experience in the helicopter in question [16].

Figure 9 - Incidents and Accidents with Pilot Error [Blumen]



With pressures due to workload, distractions, patient urgency, and inexperience, a pilot can make improper decisions in the air. Poor decisions lead to accidents. The vast majority of accidents involving a pilots decision-making skills lead to an incident involving a struck object. Seen above in Figure 9 is the breakdown of total accidents by type with additional information regarding specific human error accidents. There are a high percentage of accidents that are obstacle strikes with connections to human error. Obstacles strikes can occur during most stages of flight and there are numerous possible causes. Misinterpretation of environmental cues and improper assessment of landing and takeoff zones are the most common causes and these problems are often linked with other human error factors [16].

Table 8 - Obstacle Strikes in US HEMS Accidents and Incidents 1987 – 2000 [Veillette]

Type of Obstacle		Take Off	En Route	Approach /Landing	Ground
Wire					
	Incidents	3	1	8	0
	Nonfatal Accidents	6	1	2	0
	Fatal Accidents	1	4	1	0
Fence, tree, light					
	Incidents	1	0	8	0
	Nonfatal Accidents	4	0	6	0
	Fatal Accidents	0	0	0	0

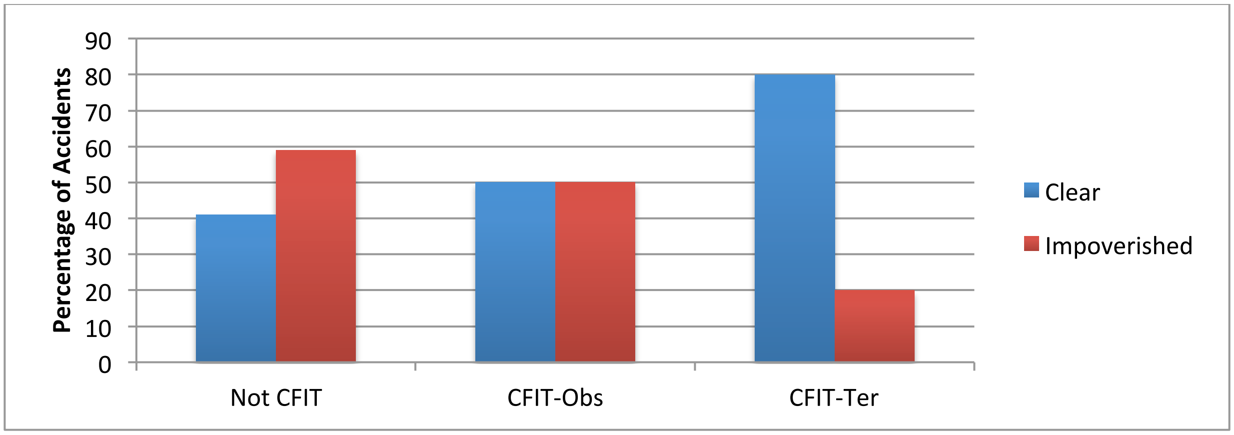
Table 8 shows a general breakdown of the accidents and incidents occurring between 1987 and 2000. In Veillette's study, it was found that 21 of the 27 obstacle-strike accidents occurred during takeoff and landing. 14 of the accidents occurred on-site and in 11 of these accidents, the pilots had attempted to obtain information regarding obstacles around the landing zone. In eight of the accidents, the pilots were given information regarding wires, but in six cases, the directions were inadequate or vague [81].

One such incident with poor decision-making resulting in a destroyed aircraft occurred on Jun 7, 1997 in Bay City, Michigan. In 18-knot winds with gusts at 23 knots, the pilot of the MBB BO 105 CBS helicopter attempted a steep downwind turn at low altitude. The right skid and main rotor blades impacted the ground during the turn causing a loss of control. The aircraft was destroyed with two fatalities [81].

Proper assessment of flight space caused a serious accident in April of 1988 in Cajon, California. An Aerospatiale AS 355F was carrying one patient in instrumental flight conditions when the helicopter struck power lines 36 feet above a roadway. The helicopter then proceeded to strike a retaining wall and clip several trees before plunging into a 70-foot-deep ravine. The helicopter was destroyed, with both the pilot and flight nurse perishing. The patient survived, as they were strapped to a full-body board [81].

Along with obstacle strikes, improper judgment, usually combined with incorrect or inadequate weather briefings, often leads to controlled flight into terrain [CFIT]. CFIT often occurs under instrument meteorological conditions or at night, and can also be attributed to inability to recognize an aircrafts relation to the terrain. This type of incident is broken down further by the FAA into controlled flight into terrain [CFIT/T] and controlled flight into obstacle [CFIT/OBS]. CFIT/T was found to result in more fatalities, as well as increasingly common during poor environmental conditions [18]. A breakdown of CFIT/T and CFIT/OBS accidents is shown below in Figure 10.

Figure 10 - CFIT vs. Environmental Conditions [Bouquet]



One such CFIT/OBS accident occurred on April 25, 2000 in St. Petersburg, Florida. A pilot was flying a MBB BK 117 along a newly established flight route when the helicopter flew into a radio transmission tower guy wire. The aircraft continued at altitude for several hundred feet before descending into a mangrove tree, killing all three people on board [16].

CFIT/OBS accidents tend to be less fatal, however CFIT/T accidents have an extremely high fatality rate. As CFIT/T accidents occur at speed, most helicopters are completely destroyed. Such was the case to a Sikorsky S-76A in June of 1999. In night instrument meteorological conditions with visibility less that a quarter mile, a pilot simply struck rising terrain, killing everyone on board [81].

Due to the nature of CFIT/OBS and CFIT/T accidents, the FAA has since required the use of terrain awareness and warning systems [TAWS] or enhanced ground proximity warning system [GPWS] on all aircraft capable of carrying six or more passengers [36]. Unfortunately, these systems are not required on HEMS vehicles. These systems are behind the current technological curve, and yet they remain expensive. The most basic systems that perform only the bare essentials are priced around $10,000 with more advanced systems going as high as $230,000. An adequate system falls between $10,000 and $40,000. These systems are not cheap, and are therefore not always practical to install on a HEMS vehicle [61].

Table 9 – Pilot Experience Prior to Accident or Incident

	EMS		**All Helicopter**	
	Average	**Range**	**Average**	**Range**
Total Hours	6307	3000-19275	6424	29-34886
Helicopter Hours	5010	27-17380	4230	8-25000
Hours in Make	753	16-3620	1273	25-8918
Instrument Hours	269	0-1647	203	0-3613
Prior 24 Hours	1.47	0-6	3	0-15

TAWS also require additional pilot training, an area already inadequately covered. Shown here in Table 9, Instrument hours are already quite low for HEMS pilots. On average, HEMS pilots only have 66 hours of additional instrument hours as all helicopter pilots. As

HEMS pilots are more likely to operate in poor weather conditions, this number should be significantly higher. As HEMS pilots undergo more strenuous tasks and find themselves in more dire situations, one would think that they would already be required to undergo additional training. Unfortunately this is not found to be the case. While total hours were comparable between HEMS and all helicopter pilots, hours in make was shown to be significantly less for HEMS pilots. Also notable, is the shortage of hours on instruments. With many HEMS missions taking place in instrument meteorological conditions, at night or in poor, additional instrument training should be required [81].

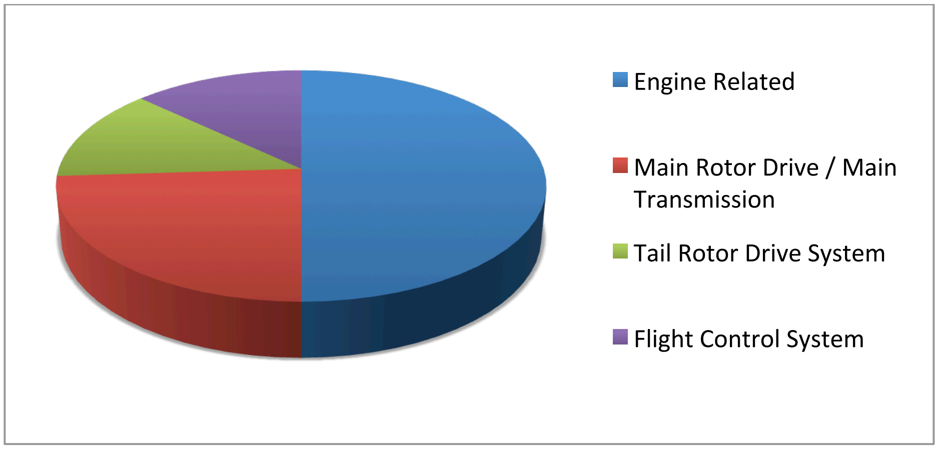
Other simple fixes can be enacted in order to reduce accidents and incidents due to pilot error. An easy solution to reduce pilot distraction would be to isolate the piloting compartment from the patient compartment. Night vision goggles could be used in combination with TAWS in order to best work in instrumental meteorological conditions. Weather briefings and more detailed information concerning landing zones could provide additional situational awareness and prevent CFIT/T and CFIT/OBS. When a copilot is unattainable, air traffic control should make an effort to stay in greater contact with the pilot in order to aid the pilot in decision-making processes.

Along with the aforementioned fixes, additional methods for alleviation of pilot error based accidents should be a priority with the frequency in which these accidents occur. Unfortunately, one of the best ways to decrease pilot error is simply better judgment, which cannot be easily taught. This means that the majority of fixes will have to come from a more controllable location.

Section 2.3.2 Mechanical Malfunction as a Major Consideration

In addition to human error, mechanical issues can be a major factor in the cause of accidents in HEMS operations. Improper maintenance, component failure, and intrusion of foreign objects can cause loss of control, loss of altitude, and a myriad of other aircraft issues leading to a collision or crash. Figure 11 below shows an overall distribution of mechanical failure related crashes. As shown, approximately fifty percent of the accidents are engine related.

Figure 11 - Probable Cause of Maintenance Related HEMS Accidents [Blumen]



In a 2002 report by Rick Frazer, of 122 accidents it was determined that 23% of all accidents were maintenance related. Frazer further categorized mechanical related accidents into four categories, with engine related causes being the broadest, and making up 50% of all maintenance related accidents. While this breakdown generalizes the actual failures in mechanical related accidents, the causes are spread across a slightly larger spectrum, shown below in Table 11 [16].

Table 10- Mechanical Failures in US HEMS Accidents and Incidents 1987 - 2000 [Blumen]

Failure		**Take Off**	**En Route**	**Maneuvering**	**Approach/Land**	**Ground**
Engine						
	Incidents		11		2	
	Nonfatal Accidents	2	2		1	
	Fatal Accidents		2			
Cowlings,						

Doors						
	Incidents	1	3		2	
	Nonfatal Accidents	1			1	
	Fatal Accidents	1			1	
Flight Control						
	Incidents		4		2	1
	Nonfatal Accidents	1	2		2	
	Fatal Accidents		1			
Transmission						
	Incidents		5			
	Nonfatal Accidents		3	1		
	Fatal Accidents		2			
Transmission						
	Incidents	1	2			
	Nonfatal Accidents				1	
	Fatal Accidents		2			

In Veillette’s 2001 study, it was shown that 26 accidents were due to mechanical failure. Six accidents were attributed to improper maintenance, seven to engine failure, six to tail-rotor failure, and six to transmission failure. Fortunately, 20 of the 26 incidents resulted in successful precautionary landings [81].

Highlighted in 2008, it was determined that nearly have of the US’s medical helicopters had improperly installed night vision systems. This is a serious issue as without adequate night vision, pilots are forced to fly in instrument meteorological conditions while operating at night. This also poses a problem when pilots attempt to read instrument displays. These improperly installed systems also cause reflections and unnecessary light sources that can interfere with a pilot’s vision. A request was made to ground all aircraft in question, and the FAA initially approved, but later a decision was made not to ground the aircraft. Apparently, the FAA decided that the negative publicity that would come from grounding HEMS vehicles was undesirable and unavoidable [33].

Other issues can stem from installation of unsuitable equipment. When HEMS vehicles are modified for installation of medical equipment, they are stripped of all excessive components including furnishings, carpeting, and equipment. New equipment is then installed such as special seats for medical staff, mounting locations for the litter, and medical equipment. Additional modifications are also made to suit a specific hospital or HEMS provider's needs. This can lead to hardware being installed that conflicts with existing hardware essential to maintaining control of the aircraft. For example, it has been found that certain heart monitors produce interference on certain radio frequencies. This interference can be so loud that it can force a pilot to lower volume on the frequency in question. If this frequency is air traffic control communications, the pilot will be unable to contract air traffic control for needed flight information and air traffic control will be unable to raise the pilot in the event of changing weather conditions or other important information [81].

These modifications may also lead to a reduction in crashworthiness, or ability of an aircraft to sustain structural integrity in order to absorb impact energy and reduce injury to the vehicle's occupants. In a 1988 study by the National Transportation Safety Board it was found that in numbers helicopters the modifications in the interior were not to FAA standards for crashworthiness. Issues were found in seats poorly attached to the floor or constructed from unapproved materials, medical equipment that was not properly restrained, and loosely stored equipment of considerable weight [81]. Poor crashworthiness can lead to on board fires post-crash. In addition, damage to a helicopter can prevent paramedics from leaving the helicopter due to debris and collapsed structural members. In three of five post-crash fires reported in

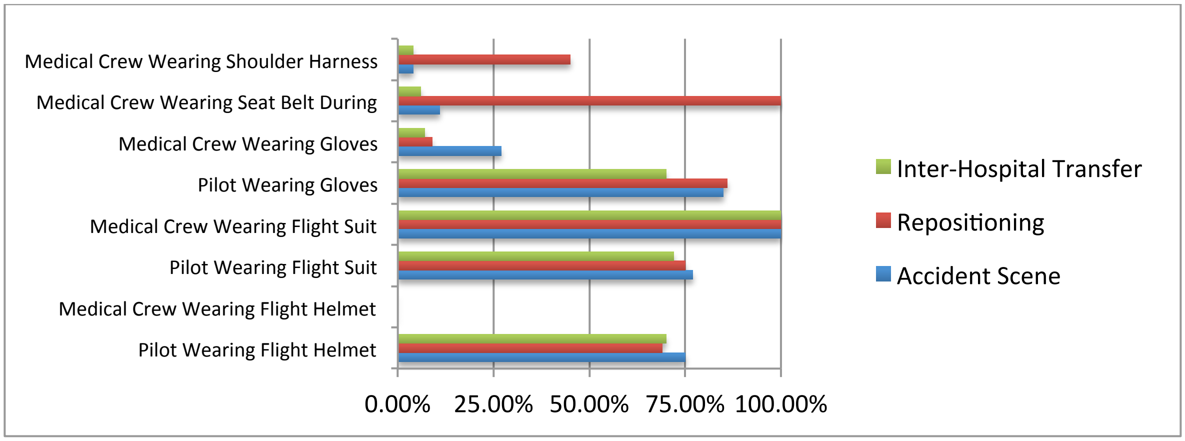
Veillette's study, medical crewmembers were unable to exit the aircraft. These issues do not translate to the pilot's compartment, as nearly all of the medical modifications are limited to the passenger cabin [81].

Table 12 - Distribution of Injuries in Survivable Crashes [Blumen]

Occupant Location	Serious Back [%]		Serious Head [%]		Minor Head [%]		Internal [%]		Fractures [%]	
	EMS	**Non-EMS**	**EMS**	**Non-EMS**	**EMS**	**Non-EMS**	**EMS**	**Non-EMS**	**EMS**	**Non-EMS**
Pilot	4.5	18	2.3	2.4	0	3.6	0	0	2.3	7.2
Front Seat	15.4	2.7	7.8	5.4	0	2.7	11.5	0	3.8	8.1
Main Cabin	28.6	9.2	14.3	1.3	5.3	1.3	7.1	2.6	10.7	5.3
Patient	14	N/A	7.1	N/A	0	N/A	0	N/A	7.1	N/A

Robert Dodd Ph.D. conducted an extensive study concerning crash survival in HEMS in 1992, shown above in Table 12. Dodd reviewed 75 EMS accidents dating from 1978 to 1989 and 147 non-EMS accidents dating from 1983 to 1989. The study found that in survivable crashes passengers in EMS helicopters have 4.5 times the risk of serious injury or death when compared to non-EMS helicopters. Also included in Dodd's research were testimonies from survivors of the crashes in questions. Twelve medical crewmembers reported that they sustained injuries during the crash from collisions with medical equipment inside the helicopter. This equipment included portable radios, medical panels, oxygen tanks, and the stretcher [16].

Figure 12 - Use of Protective Clothing by US HEMS Crews 1995-2000 [Veillette]



Additionally in crashes, misuse of protective gear can lead to injuries that might have been possibly avoided. Because of their inflight duties, EMS crewmembers are often not seated during impact. Veillette also covered this in his study (See Figure 12), investigating 433 cases of HEMS crews at three different states of flight: at the scene of the accident, during repositioning, and during inter-hospital transfer.

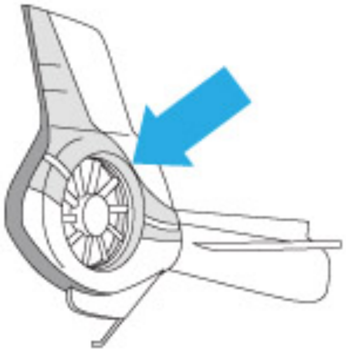
While some investigative issues such as pilot crew wearing gloves are seemingly insignificant, other problems such as pilots wearing flight helmets are very important. Having a helmet in place during an accident will significantly reduce head and neck injuries. In addition, visors can help limit injury as studied in an investigation by the US Army Aeromedical Research Laboratory. This study covered 1,035 Army helicopter accidents dating from 1989 to 1996. Visors were used in 459 cases and prevented injuries in 102 accidents. Visors also reduced the severity of injury, as the data showed that the fatality rate was nearly three times higher among pilots who kept the visor up as compared to pilots who had the visor down. Unfortunately as shown in Veillette's study, the importance of helmets does not always translate to the emergency personnel, as none of the EMS crewmembers wore a helmet during operations [81].

Both pilots and EMS crewmembers both were prone to use of a flight suit. While this helps in fire and abrasion related injuries, a flight suit does not provide enough protection as compared to a helmet used in conjunction with a seat belt and safety harness. Ideally, a flight suit would be chosen with favorable qualities in flammability, comfort, abrasion resistance, fabric strength, durability, and useful service length. A known fabric cannot fulfill all of these characteristics [81].

The US Army favors use of a fabric known as Nomex. Nomex has been shown to reduce thermal injury through favorable heat transfer characteristics. Able to withstand temperatures of 300 degrees Fahrenheit, Nomex was used in 72% of all flight suits. In a 1999 NEMSPA survey, 42% of pilots said that helmets, Nomex flight suits, and leather boots and gloves should be mandatory equipment for HEMS crews [81].

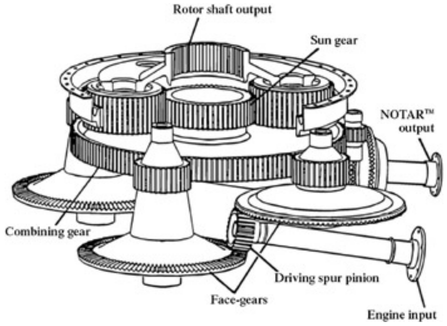
Crashworthiness aside, accidents and incidents caused by improper maintenance can be devastating. Coupled with time pressures to get off the ground quickly to reach a patient, maintenance issues can often be overlooked. Some maintenance inspections can take up to 500 hours after major repairs and portions of these inspections are done with the helicopter in flight. If tools used to detect failing parts do not function properly, issues can arise. One such case occurred on December 18, 2000 in West Mifflin, Pennsylvania. An Aerospatiale SA 365 was undergoing a 500-hour inspection after replacement of tail-rotor components. During a flight check, the pilot and maintenance technician hear a bang and control of the tail-rotor was lost. The pilot was unable to land normally without tail-rotor control and was forced to execute a running landing, a maneuver used when the helicopter is unable to maintain a hovering position for normal landing. The landing did not go smoothly and the tail boom broke away from the main fuselage. It was found that the fenestron, the shroud that covers the tail rotor [See Figure 7], and pitch-change servo-actuating rod were not connected to the actuating bell crank. This left the pilot unable to control the rear rotor [16].

Figure 13 - Fenestron



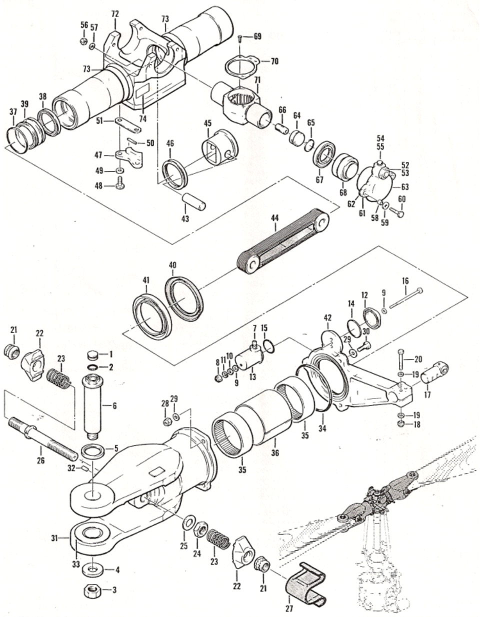
Improper installation of replacement parts can also cause problems. In engine and transmission components especially, failure of a component due to poor installation can lead to crashes. Transmission issues cause a crash in October of 2000 to a HEMS crew based out of Burlington, North Carolina. Right before landing at a medical facility the main-transmission oil-pressure warning light lit and the pilot had a technician check the aircraft. No excessive oil leaks were found and the warning light was reset. A ground and hover check produced no further issues and the helicopter was cleared for departure. In flight, the helicopter made a steady droning sound and a thumping noise and the helicopter lost altitude and struck trees, busting into flames. After inspection, it was found that the gears in the combiner gearbox were damaged and that the transmission-oil-pump shaft was separated near the midspan. [See Figure 8] [81]

Figure 14 - Helicopter Transmission Showing the Combiner Gear



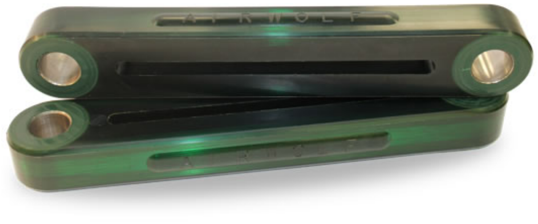
Mechanical failure can also come as a result of metal fatigue. Being made almost entirely of various metals and synthetics, all components of helicopters are subject to continuous and cyclic stresses that can lead to fatigue, reducing the strength of the members in question. Factors such as stress levels, frequency of stress, temperature change, and material type can add up to lead to crack growth, ducting, and eventual failure.

Figure 15 - Parts Breakdown for BHT Model 206A/206B Showing Location of Tension-Torsion Strap – Component number 44.



Corrosion led to three fatalities in a crash in July of 1999. A BK-117 commissioned by Hermann Life Flight in Houston, Texas was on approach to a refueling site when witnesses saw pieces of the main rotor separate from the helicopter. Loss of control and altitude ensued and the helicopter was destroyed. Post-accident investigation determined that corrosion in the tension-torsion strap resulted in partial failure of the strap and the strap and main rotor blade separated from the helicopter [16]. Tension-torsion straps are extremely ductile straps of material that hold rotor blades to the drive mechanism [See Figures 9 & 10].

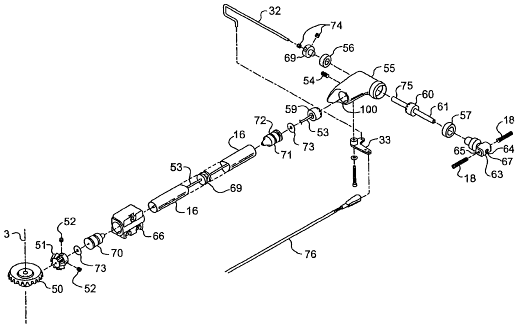
Figure 16 - Tension-Torsion Strap



They are exceptionally strong, and can withstand tremendous centrifugal loads, while still accommodating of axial motion required for blade control. When a tension-torsion strap fails, the blades of the rotor are no longer attached to the drive mechanism. This releases the rotor blades, which can lead to catastrophe.

While less common than corrosion, thermal damage can also cause issues. Most dangerous in the transmission and engine, overheating can cause engine failure, abrasion in the transmission, and problems with the flow of important fluids. Overheating can be caused by lack of or improper coolant, debris blocking the flow of coolant, and buildup of heat in the engine compartment. Thermal accumulation can lead to fires, and most importantly, component failure. A poorly cooled engine or transmission that fails will lead to damage and eventual failure.

Figure 17 - Transmission for Rear Rotor



Thermal damage caused the destruction of a MBB BO 105C in September of 1995 in Texas. While cruising at altitude, the pilot heard an unusual whine, followed by a snap and increased vibrations coming from the engine and drive systems. The number one engine fire light illuminate and the pilot smelled smoke. After touching down in a shopping mall parking lot, the crew exited the helicopter as smoke entered the cabin. The main-transmission lower housing was later inspected to reveal the separation of the drive shaft for the engine from the transmission-input-shaft flange [See Figure 11 components numbers 16, 71, 72, & 73] [81].

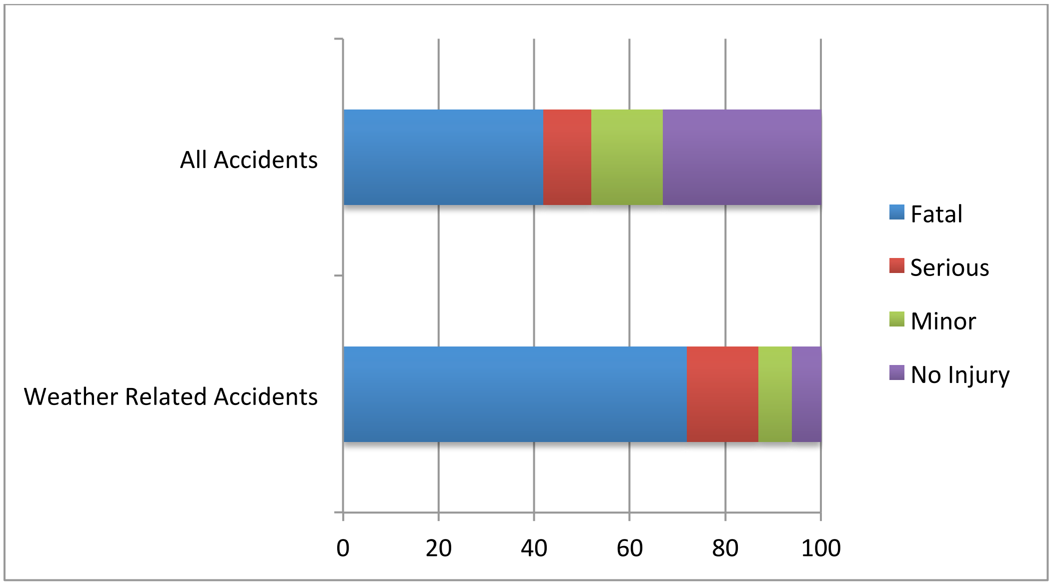
While less common and more unpredictable than human error factors, accidents and incidents relating to mechanical failure are just as deadly. Unfortunately, mechanical failure is difficult to account for and avoiding injury in certain situations is difficult. Requiring more frequent engine, transmission, and rotor inspections can decrease the number of failures due to overlooked material fatigue. Additional time spent in stress testing materials for response to temperature changes and corrosion would lead to a decrease in specific failure cases. Development of alternative systems of restraining straps and harnesses would allow EMTs to move about the cabin while maintaining adequate care of the patient. While not the only issue causing accidents and incidents, mechanical failures cause some of the most serious accidents and steps can be taken to avert further crashes.

Section 2.3.3 Environment and Surroundings as a Major Consideration

Along with mechanical and human factors, one of the most prominent factors in the cause of HEMS accidents is environmental and other surrounding atmospheric conditions. Most notably, weather effects can force operations in instrument meteorological conditions, which pose increased risk to pilots, medical staff, and patients in transport. Connections have also been found between night missions and increases in accidents. When combined, night missions in inclement weather are prime candidates for accident. Also important is the phase of flight, with a high percentage of accidents occurring during takeoff and landing. Less impactful, but still relevant is conditions on and around the landing zone.

Easily the most prevalent and most obvious environmental factor in cause of HEMS accidents is adverse weather conditions. A 1998 study by the NTSB determined weather hazards to be the greatest single threat to HEMS operations. Between the late 1980s and mid 1990s, it was determined that 32% of accidents were related to weather [14]. Weather accidents also prove to more often result in fatalities than non-weather related accidents. In Frazer's 1999 report, he found that of 23 weather related accidents, 17 of them resulted in deaths. After further investigation, Frazer found that 76% of weather accidents had fatalities, with 64% leaving no survivors (See Figure 18) [16].

Figure 18 - Severity of Injury All Accidents vs. Weather Related 1982 - 1998 [Blumen]



The FAA does have limitations for operations in poor weather concerning the visibility and minimum altitudes at which operations can proceed, as shown below in Table 13. These regulations govern the minimum ceiling (lowest cloud height) and minimum visibility in which missions can be accepted.

Table 13 - Ceiling and Visibility Limitations as Stated by The Commission of Accreditation of Medical Transport Systems

Condition	Area	Ceiling	Visibility
Day	Local	500'	1 mile
Day	Cross Country	1000'	1 mile
Night	Local	800'	2 miles
Night	Cross Country	1000'	2 miles

Ceiling and visibility requirements also vary for day and night conditions, as well as dependence on local vs. cross-country flights, with local defined by agency, up to 100 miles or more in certain cases, as shown in Table 13. Failure to adhere to these regulations forces pilots to fly in instrumental meteorological conditions [16].

Weather accidents are broken down into three main categories: controlled flight into terrain [CFIT], loss of aircraft control, and in-flight collision with an obstacle. When associated with weather, these accidents are often connected to unplanned entry into instrument meteorological conditions. Reduced visibility, loss of situational awareness, and disorientation all contribute to weather related accidents and incidents.

Reduction of visibility forcing operations in instrument meteorological conditions is a foremost perpetrator. Depending on how quickly the pilot can react to unplanned entry into poor conditions, as well as whether or not a helicopter has a terrain awareness and warning system installed, objects and terrain can quickly come up on a pilot leading to a crash. Reduction in visibility can come from clouds, fog, and precipitation. Even when a pilot is aware of adverse weather conditions, they are sometimes unable to maintain control of the vehicle [81].

One such case occurred in Amarillo, Texas in March of 2000. The operation was at night in heavy fog and the scene of the accident was reached without issue. However, after takeoff, the pilot failed to establish communication with the ground or air traffic control. The wreckage was not found for five hours due to the fog in the area. The helicopter was destroyed, with four fatalities. Presumably, the pilot lost situational awareness and controlled flight into terrain occurred [81].

Wind is another weather condition that can cause a HEMS accident. Helicopters have large surface areas and are built so that they are lightweight while maintaining strength. Strong crosswinds can push helicopters into undesirable positions. In flight, strong wind is often an instigator, leading to pilot loss of control. On the ground, or shortly before landing/after takeoff, strong winds can push a helicopter into obstacles, or tilt the aircraft over entirely. Rotors can strike the ground, throwing debris and pieces of the rotor blade into the air at high speeds. These airborne particles are a danger to ground crew, pedestrians, and property in the area of a landing zone.

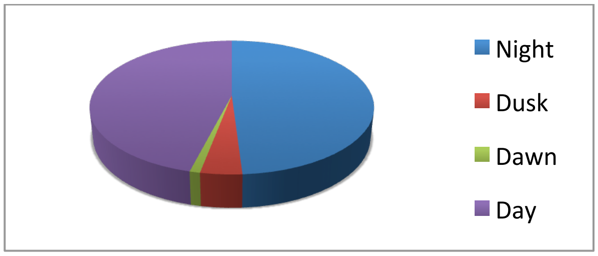
One wind caused incident occurred in Great Falls, MT in 1999. A HEMS crew was responding to an accident at a ski resort. Due to the direction of approach, when the pilot wanted to take off, there were trees directly in front of the helicopter. The pilot opted to turn the helicopter so takeoff could occur downslope. During rotation, the pilot felt the tail turn abruptly due to a gust of wind. The pilot attempted to maintain control and return to the landing zone, but the tail rotor struck a lift tower. The helicopter landed hard with substantial damage [14].

Unfortunately, official weather reports are not always available, and due to time pressures, pilots have left before receiving the entirety of a weathering briefing. With incomplete or improper weather briefings, a pilot may unknowingly be headed into poor weather conditions. Some weather reports were found to mention “chance of instrument meteorological conditions.” This lack of specificity was found in 11 of 14 accidents studied by the NTSB. Without adequate weather briefings, chances of accident increase, especially in nighttime operations [81].

An example of an accident cause by incorrect weather information occurred in Cincinnati, Ohio in May of 2000. The pilot was on approach and observed the windsock on the landing zone was extended, indicating a slight breeze. While in final landing descent, the pilot heard a loud noise from the rear of the aircraft and lost tail-rotor thrust. The helicopter crashed hard into the landing pad. Later examination of the windsock showed that it was caught, and when freed it extended straight out, indicating a stronger wind than the pilot had anticipated [81].

With low visibility, accidents can be more severe. With controlled flight into terrain accidents, often terrain comes up suddenly under the aircraft. This means that the helicopter impacts at high speeds, as the helicopter was thought to be cruising at altitude. These crashes are more serious and lead to more fatalities.

Figure 19 - Day vs. Night HEMS Accidents [Blumen]



Operating at night by itself poses an issue to HEMS missions. As shown above in Figure 19, over fifty percent of HEMS accidents occur in night, dusk, or dawn conditions. All these times translate to low light condition, requiring possible use of night vision goggles. If night vision equipment is improperly installed or utilized, pilots will be unaware of obstacles, terrain, and other hazards in the airspace. While the majority of HEMS operations occur during the day, accidents are split nearly evenly between night and day operations [81]. During night operations, is it also important to keep a properly lit landing zone. A landing zone with insufficient light makes landing more difficult for the pilot.

Links have also been found between accident rates and phase of flight. Higher percentages of accidents occur during takeoff, landing, and during cruise, with maneuvering and repositioning having a lesser frequency. This is associated with the frequency of accidents involving obstacle strikes. During takeoff and landing, helicopters are flying at lower altitudes and are more prone to obstacle strikes. Guy wires for radio towers and electrical lines are both easy to miss by pilots and ground crew and are frequently involved in accidents.

Environmental and surroundings complications are usually coupled with other accident causes. Changes in weather conditions can result in delayed, or incorrect pilot reactions leading to crashes. Night operations will cause accidents when joined with improperly equipped vehicles. Along with human error and mechanical malfunction, the causes of HEMS accidents are widespread. Reduction in accidents will take extended investigation and attention to specifics.

Chapter 3. Reducing Accidents, Costs, and Transport Time in HEMS

Section 3.1 Cost Reductions and Areas of Further Research

Section 3.1.1 Altering Current Costs

The current costs associated with maintaining, operating, and dispatching a helicopter ambulance are significantly larger than ground based alternatives. This severe disconnection in cost inhibits the potentially life-saving transportation method from being widespread and available to an entire national population on a first-response basis. It is therefore essential that the costs associated with helicopters and helicopter ambulances be reduced to amounts that are affordable for both hospitals and patients that request their services.

The ideal reduction in costs would revolve around current standing costs regarding operation and maintenance. Helicopter acquisition costs are another method of cost reduction, but these costs are primarily out of the control of the hospital; the only exception is price negotiation during procurement. Table 4 from Section 2.1.3 is of particular interest, then, and each category will be examined for possible cost reductions on a topic-by-topic basis. This will provide an in-depth analysis while also allowing for piece-wise implementation of cost-saving measures.

Item T-1 of the Annual Direct Operation Costs is Fuel and Other Fluids. The prices associated with the fluids and fuels required to operate a helicopter are dependent on market forces beyond the control of any hospital. The fluids used in the jet engines are specialized for high temperature gas turbines, and as such the quality may not be compromised upon. The only area for price reduction would be to ship jet fuel from another area, such as a different airport that has a lower jet fuel price. The price difference would have to be substantial, however, as additional logistical equipment and service would need to be employed, raising additional costs. If a substantial difference is found which warrants the additional logistical costs, the fuel could then be stored in bulk to maximize the benefit of the cheaper fuel and to offset the logistical costs. As an example, on March 18, 2013, the price of Jet A fuel at Worcester Regional Airport is $6.80 per gallon, where if the fuel were to be trucked over to Worcester from Barnes Municipal Airport in Westfield/Springfield, MA, the price of Jet A fuel is $4.75 per gallon. This would produce $379.25 in savings prior to the expenses produced in transporting the gas when filling a 185-gallon helicopter fuel tank. Compared to Logan International Airport, this method would produce $726.13 in savings prior to transportation costs per filling of the same tank. The potential for savings are dependent on the availability of inexpensive truck transportation, however, and a deal with a trucking company should be sought.

Alternative propulsion methods would provide a different way to reduce fuel costs in helicopters. One alternative that is approaching plausibility with current technology would be electricity and electric powered motors. The primary strength as related to fuel costs of electricity over fossil fuels is the efficiency of the motors being used. Current internal combustion style engines have efficiencies anywhere from 20% to 30% compared to current electric powered motors, which can have efficiencies well above 90% or 95%. The efficiencies coupled with cheap electricity costs would lead to a substantial reduction in fuel costs.

The second item in the list is the crew costs. Crew costs are unique in that they can be completely controlled directly by the hospital. The hospital is able to pay the EMTs as much or as little (keeping minimum wage in mind) that it wishes too. Evidence has been found to suggest that an increase in pay, including incentive pay, increases productivity in workers. Therefore, a reduction in pay may result in a reduction in productivity, which for a field such as healthcare is unacceptable, especially in a high-risk, high-demand field such as the HEMS program. A reduction in pay would also likely result in a loss of morale and manpower due to other hospitals providing competitive pay rates which would be more attractive to EMS personnel. It is thus not in the interest of the hospital to reduce the pay of associated workers, nor would the saved expenses be worth the consequences.

Next on the list is the aircraft lease or rental. The costs due to the lease or rental are directly or proportionally related to the acquisition cost of the aircraft from the manufacturer. Outside of negotiations over price between the hospital and the supplier, this is out of the control of the hospital. The other method to influence the costs associated with the lease or rental would be to choose a cheaper and often smaller aircraft. In order to meet the needs of the helicopter EMS program, it would not be advisable to substitute the available fleet for smaller craft. The hospital already fields an aircraft of the smallest class possible while meeting EMS demands, with larger aircraft to meet other varying situation specific demands. The remaining opportunity for a reduction in this price field would be in the form of new technology and products from helicopter manufacturers. New technologies could reduce the operating costs of aircraft while improving safety, allowing helicopters to become more viable personal transportation methods. This would prompt additional research into cheaper manufacturing techniques, lowering production costs, which could lead to savings being passed onto the consumer. The most likely and important source of reduction in this category would be in the form of new technology.

Improvements in the expenses due to maintenance are in a similar field to the leasing and rental expenses. Currently hospitals employ a minimum of maintenance workers to meet the harsh helicopter maintenance demands. Similar to the aircrew, it would not be advisable to reduce the pay to these maintenance workers for the same reasons: morale and incentive. Reductions in maintenance costs will sprout from new maintenance methods and technology. Current methods require extensive examination and a high level of preventative care, which requires a highly skilled worker to execute. These methods may be able to be optimized to reduce the demands of the job, resulting in a quicker execution of the required work and thus less manpower required to service a fleet. New preventative care methods may also be developed which could prolong the life of high-maintenance or critical parts that must be replaced well before they are subject to damage from excessive use. Such methods may employ crack filling technologies to fill the microscopic surface cracks that develop in the components used on helicopters. Methods such as these would lead to a reduction in costs associated with the acquisition of replacement helicopter parts. Additional research into the methods and tools of helicopter mechanics is required to find potential cost saving methods.

The next variable expense category regards expenses due to insurance. Insurance costs have an inverse relationship with the safety of the aircraft and a direct relationship to the dangers faced by the aircraft. Therefore, in order to make it possible to negotiate lower insurance rates with insurers, it is necessary to pinpoint the elements that cause a helicopter crash during operation and to actively reduce these causes. If the aircraft are made safer, it would also produce a reduction in legal costs associated with any crashes or injuries to crew. Additionally, it is logical that the fewer helicopters that are destroyed, the few that the hospital must acquire, saving money by minimizing the number of times the acquisition costs must be paid. In the case of a crash, insurance would not cover the acquisition price that the hospital paid, but rather the value of the helicopter at the date of the crash. Due to the depreciation of helicopters being an inverse relationship between age and value, there is a period shortly after procurement where the aircraft quickly depreciates in value. Therefore, it is in the interest of the hospital to maintain a helicopter for the longest period that it can due to the decrease in the rate of depreciation of the aircraft. Therefore, if a helicopter crashes shortly after it is obtained by a hospital, the hospital would lose a large amount of money relative to the value perceived by the hospital. If the hospital maintains the helicopter for multiple years before an incident, not only will insurance costs be lower due to evidence suggesting a higher level of safety and lower levels of danger, but also the hospital will lose less money in the crash because it obtained value from the aircraft through operation. Safety is thus one of the most important improvements that a hospital could implement, as the benefits are two-fold.

In summary, the possible reduction available for hospitals to achieve at present time consist of shipping of fuel from a less expensive location and implementation of safety measures to reduce the number of accidents and lower insurance rates. These price reductions are only marginal, however, and will not have an impact that is required to create widespread, efficient use. The potential to proliferate helicopters and their related services lie in further research in the fields of efficiency, safety, and manufacturing. With continued research in these fields, it may be possible to create inexpensive helicopters that are available to the public.

Section 3.1.2 Electric Powered Helicopter

In order to achieve the primary goal of our research, the expansion and dominance of helicopter ambulance use, innovation must occur regarding the helicopters themselves. In order to make HEMS a more plausible option for widespread hospital use, the vehicles must be substantially more efficient and cost effective than current helicopters. Further improvements over the current systems must also be present in order to attract consumers, improvements in fields such as noise emission and safety. One possible solution would be an electricity-powered helicopter based on emerging technologies and current standards. In order to exemplify how such a helicopter would impact an HEMS program, we examine the benefits and plausibility of an electric helicopter system in the form of an American Eurocopter EC135.

When comparing electric driven motor systems and internal combustion based systems, one dominant concern is the comparison of operational range of the electric system to the internal combustion system. When switching from an internal combustion based system to the electric system, the operational range should be the same or comparable, assuming the internal combustion helicopter was chosen with the required operational range in mind. If the electric based helicopter is unable to meet the range specifications provided by the consumer, the electric helicopter will not be a viable option, making it of prime concern to manufacturers. It is therefore important to understand the capacities of current and emerging batteries as well as their energy densities so a comparison to jet fuel can be made.

In order to compare jet fuel to battery power sources, the respective power output of the two energy sources must be computed and compared to the power output for the current motor in the EC135. The EC135 uses 2 Turbomeca Arrius 2B2[26] which has a continuous power output of 540 kilowatts each. The specific energy for Jet A fuel provided by BP is 43.02 megajoules/kilogram and when applied to the 185-gallon fuel tank (which weighs 574 kilograms filled with Jet A), the combustion engine has an energy capacity of 24.7 gigawatts.

Equation 1- Combustion Fuel Energy Capacity

$$43.02\,\frac{MJ}{kg}\times 820\,\frac{kg}{m^3}\times\frac{1\,m^3}{264.172\,gal}\times 185\,gal = 24704\,MJ$$

This provides for 12.7 hours of flight assuming perfect efficiency.

Equation 2 - Combustion Engine Flight Time - Perfect Efficiency

$$24.7\ GW \times \frac{1\ sec}{540\ kW} \times \frac{1\ hour}{3600\ sec} = 12.706\ Hours$$

Assuming 30% efficiency, the 12.7 hours becomes 3.8 hours, which is close to the provided maximum endurance without reserves of 3.6 hours provided by American Eurocopter, meaning the efficiency in reality around 30% [27]. Comparing the perfect efficiency to their provided endurance yields an efficiency of 28%.

When producing the power source for the electric helicopter, the weight of the battery should be comparable to the weight of the fuel. Therefore, the theoretical battery will weigh 574 kilograms. One emerging battery that has an exceptionally high theoretical specific energy is the lithium oxygen battery. This battery has a specific energy of 3505 Watt*hours/kilogram. Using this type battery a helicopter, assuming the same power output as the internal combustion engine, would be able to operate for 1.03 hours assuming perfect efficiency.

Equation 3 - Battery Powered Flight Time

$$\frac{3505\ W * hour}{kg} \times 574\ kg \times \frac{1\ sec}{540\ kW} \times \frac{1\ hour}{3600\ sec} = 1.03\ hours$$

The efficiency of electric motors are able to exceed 95% however, so applying a 95% efficiency the helicopter would be able to fly for 0.98 hours.

This theoretical helicopter using this type of electric engine and battery yields a flight time, which is only about 27% of the combustion engine counterpart. While significantly lower, it could be coupled with additional technologies, which reduce the necessary power output of the helicopter. One such method would be to coat the helicopter blades with an ultra-low friction material. Such a coating would reduce the drag experienced on the blades during operation, lowering the required power output of the engine to maintain the same number of rotations per time unit. Another method would be to raise the efficiency of the motor. Both of these methods would only provide marginal increases in flight time, but together the effect would be noticeable.

A switch to an electric engine would have many benefits. The two benefits that stand out the most are the reduction in fuel costs and the reduction in noise produced by the aircraft. The price to fill up the aircraft at current jet A fuel prices in Boston via General Edward Lawrence Logan International Airport is calculated at $1598.59.

Equation 4 - Combustion Powered Fuel Costs Per Full Tank

$$\frac{\$8.641}{1\ gal} \times 185\ gal = \$1598.59$$

This price provides for 3.6 hours of flight time, resulting in an average of $444.05 per flight hour. Comparing this price to the price resulting from using the 2012 NSTAR electric rates in Boston, MA for large NEMA businesses (the more expensive of the large business classes to provide a worst case scenario for hospitals), we can see a large reduction in fuel costs. Large NEMA businesses are charged $0.05553 per kilowatt hour, resulting in $111.72 to fill up the batteries calculated above.

Equation 5 - Battery Powered Power Costs

$$\frac{3505\ W * hour}{kg} \times 574\ kg \times \frac{\$0.05553}{1\ kWh} \times \frac{1\ kWh}{1000\ Wh} = \$111.72$$

These batteries resulted in 0.98 flight hours, producing a $114 flight hour via electricity. This is roughly a quarter of the price to fly a combustion engine helicopter.

The other discernible benefit of having an electric driven power source in a helicopter is a significant reduction in the amount of sound that the aircraft emits. An analog can be drawn to electric cars and their noise emissions in comparison to cars relying on oil-based fuel. Combustion engines rely on controlled fuel ignition and the resulting expanding gasses to drive a shaft, which produces an excess of noise. This is coupled with the noise that is produced by the expulsion of the gasses from the vehicle as exhaust, which causes vibrations and carries some of the engine noise. Electric motors do not produce the degree of noise that combustion engines produce because they operate using motors, not the expansion of gasses. The operation of a magnet itself produces no noise; the spinning shaft due to the friction and vibration produces the noise that an electric motor produces, which would be present in combustion motors as well. The electric motor eliminates the exhaust and inherent motor noise, however, due to the replacement of fossil fuel-based gas expansion with silent magnetism. This reduction in noise will produce an environment more conducive to patient care by improving both the working circumstances for the EMTs and by creating a more comfortable environment for the patient.

Helicopters by regulation are loosely limited in the level of noise that they can create. FAR limits helicopters to between 108 and 110 effective decibels from a stationary ground measurement point. This means that levels experienced by the occupants of the aircraft may exceed these levels by a significant amount. These noise levels create an environment that is not conducive to intensive care that EMTs are likely to provide. It has been found that levels in various hospital rooms can approach 80 dB, which negatively affects the nurses' performance, health, and anxiety levels while also producing complaints from patients [59]. Since the levels in helicopters are significantly above these hospital levels, it is likely that the performance, health, and anxiety levels for the EMTs working in the helicopters are further affected by the noise, more so than the nurses. Due to the severity of the patient conditions that helicopter ambulances are used for, these noise levels are unsafe and need to be lowered to raise the level of patient care. Electricity based helicopters are one method that can be used as a solution to this problem.

The benefits of an electrical helicopter are vast, and are therefore of great use to a hospital or EMT staff. Further research into the field is necessary if an electric helicopter is to be produced. Hospitals should monitor the development of such helicopters as they will both reduce the operating costs of the aircraft themselves as well as raise the level of care that the patient receives.

Section 3.2 Reducing Transport Times

Section 3.2.1 Increasing Designated Landing Zone Sites

Another problem discussed was the number of designated landing zones in the United States. Only having designated landing zones at hospitals does little good when trying to land near accident scenes. We also want to cut down on the need of moving the patient too many times, from accident scene to ambulance and the ambulance to helicopter.

One possible solution is to designate more areas of land, which fits the criteria of a landing zone, as a landing site. There are already plenty of locations that fit the description of a landing zone in suburban areas, such as parks, athletic fields, and parking lots, but by giving it a specific title of a landing zone that means it will be maintained as such and it would prevent towers, telephone wires, trees and such from being introduced to that area. This is a solution for more country and suburban areas of the country where they have the necessary space to conduct a helicopter landing.

For a city, due to the tall building and lack of extra space, it would be more complicated to implement a landing zone system. However, four lane highways and roadways are the perfect size for a helicopter to land. There are three possible solutions for integrating helicopter landing in major cities. The first suggestion would be to implement a system similar to the one currently used when a train is passing through. When a driver approaches a train crossing and the train is on its way, a barricade comes down, preventing the car from driving in front of the train. A very similar barricade system can occur on city roadways and intersections that are large enough for a helicopter landing. When a helicopter approaches the barricades come down at the intersection. The only difference would be the emergency personnel monitoring the landing area. Current problems with this plan would be the cost of installing barricades at viable intersections and the amount of time needed to land, transfer the patient, and depart from the landing site. To help ease this problem traffic would be diverted away from the landing zone as best as possible with the city conditions.

Figure 20 - Train crossing gates that may be adapted for use for road closures for helicopter landings.

Another suggestion is to integrate a system with the current procedures used at four-way intersection when an ambulance is coming. In cities, when an emergency vehicle is on route to pass through the intersection, all four lights turn red and a spinning strobe light signals the approach of the vehicle. This method is more cost effective than the barricades because it's using existing technology in order to do a similar job. When a helicopter is in route to touch down in your intersection, all four lights will turn red and the strobe will signal the approach of the helicopter. Again, emergency personnel will be on scene to monitor and insure the safety of not only the patient being transferred, but the members of the public as well.

The final suggestion to increase the number of available landing zones in the United States would be to implement a system similar to the one use for vertical lift bridges. Vertical bridges have an implemented system that stops traffic in order to let the road rise so a ship can pass under it. A similar process can occur where a patient transfer occurs when the roadway is raised and then after the helicopter departs the road settles back down again. The main problem with this possible solution is there currently aren't many vertical life bridges that allow for the dimensions needed to create a landing zone.

Figure 21 - Concept bridge that included helicopter-landing pad.

The main problem with all three of these solutions is the cost necessary to implement them in the cities. The public would also see an increase in traffic due to the amount of time needed to secure the site, land, transfer the patient, and take off. The solutions would be good short-term emergency solutions, but ineffective in the long run.

In order to have the long term solutions, a law would have to pass declaring any new buildings being built within a city over three stories high, must be able to accommodate and withstand the impact of a helicopter landing on the roof. By implementing this law, it would guarantee all newer buildings would be able to act as a designate landing zone if the need should arise.

Section 3.2.2 Improving Transportation Time

There is a high cost of operating and maintaining a helicopter for medical purposes and while we do not want to use this service frivoulously we believe it can be improved. It is important to increase not only awareness injuries that call for an aerial ambulance, but also improve upon the transportation time for HEMS.

Very few people outside the emergency first responders know the appropriate time to call an air ambulance to the scene of an accident. If we can better educate the public on how to describe the state of the paitients to the 9-1-1 dispatchers, then crutial minutes can be saved in dispatching HEMS. As stated earlier, when first responders arrive on scene they assess patients with the acronym MARCH. Every second matters when dealing with a critical patients and a greater awareness and better informed public would allow for a more efficient first response system.

Our suggestion would be to create an index card to distribute to the general public to keep in their cars. On it the card would contain questions to ask the paitent in order to better inform the 9-1-1 dispatcher. Questions would include:

- Is the person responsive?
- Are they breathing?
- Are they bleeding? If so, how much and where?

If the person is able to respond, you can also ask:

- Did you hit your head?
- What hurts the most?

These are all critical questions to find out when informing the dispatcher of the accident, because then the right medical personnel can be sent to the accident scene. This card would not only be useful for helping inform when HEMS is needed, but all medical personnel.

The critical care question card would be used to help get first responders as much information from dispatch as possible in order to better prepare them for the scene they're about to emerge onto. The more information being circulated, the better the overall transport time for the patient.

Figure 21- Helicopter Transporting Patients from Accident Scene

HEMS is rarely the first responder on the scene of an accident. In 2011, of the 86 accidents HEMS responded to in Oklahoma, the unit was never called to the scene as a first responder. This lead to a median response time of 31 minutes. Our goal is to help increase the rate of patients survival, by decreasing response time. The key to this is to get the patient emergency care within one hour of an accident.

Another change to the HEMS system that can lead this quicker response time and better inflight care for the patients is to have HEMS on standby for all accidents involving multiple patients outside of a twenty minute radius of all major trauma hospitals. The reason for being more than twenty minutes from a hospital is because within twenty minutes of a hospital, the first responders to the scene are more likely to transport the patient to the hospital quicker than it would take the HEMS crew to respond to the scene.

Section 3.3 Decreasing Likelihood of Accidents and Incidents

Section 3.3.1 Identified Problems

Of the myriad of problems that are present in HEMS operations only certain issues are targetable for resolutions. Some issues, including most environmental factors, are not directly within the control of HEMS pilots or operations and attempts must be made elsewhere to indirectly solve the issue. In nearly all other areas, maintenance related and human error related are directly targetable for resolution.

For the problems with viable solutions, there are three main areas: improvements in equipment, improvements in pilots' situational awareness, and improvements in procedures. Equipment improvements are likely to be the most expensive as they mostly deal with upgrades to obsolete components, or introduction of entirely new components. Situational awareness fixes are mostly targeting issues due to human error and involve pilots, and their operations. Procedural items fall mostly under the category of maintenance related issues and deal with inspections, checklists, and standards.

Equipment related issues mostly fall under lack of equipment for specific tasks, and therefore are often quite expensive as they involve installation of new equipment. Unfortunately, while this means many of the problems due to inadequate equipment are not financial viable. The lack of Terrain Awareness and Warning Systems [TAWS] and/or Ground Proximity Warning Systems [GPWS] in most HEMS vehicles could easily rectify many problems. Unfortunately the FAA does not require TAWS/GWPS on all air vehicles. The most recent amendments concerning TAWS/GWPS by the FAA were proposed in 2001. Amendments 91-263, 121-273, and 135-75 went into effect on March 29, 2001 and required that all US registered turbine-powered air planes capable of carrying six or more passengers, excluding the pilot and copilot, be equipped with a FAA-approved TAWS. These regulations are targeted at commercial passenger airplanes and do not cover helicopters for commercial, recreational, or emergency use. [20] After a set of safety hearings in 2009, the National Transportation Safety Board put into place requirements that HEMS vehicles required thereafter would need to have TAWS installed. Unfortunately this does not cover vehicles manufactured before the regulation went into place, and as medical helicopters are extremely expensive, many vehicles in operation are still not equipped with the proper systems [9].

A similar issue lies with night vision goggles [NVGs]. The FAA, NTSB, or any other association does not require NVGs for use in HEMS in any capacity. After the aforementioned safety hearings in 2009, it was only recommended with added considerations for the use of NVGs. Vehicles with NVGs as well as approved TAWS were to be allowed lower flight ceilings, as well as less strict travel restrictions during night time operations. NVGs are a much cheaper equipment cost than TAWS/GWPS, but unfortunately, the FAA and NTSB do not feel that enough research has been done to warrant an amendment to regulations [9].

Other equipment areas that are targetable can be found on landing sites and surroundings. Landing site regulations do not govern much besides the size of the site and that it be relatively clear of obstacles and other possible interferences. Even the most ideal landing site under current regulations is no more than a large, well-lit field. Currently, landing sites are structured to avoid collision with obstacles in clear weather conditions. Enough HEMS operations take place during inclement weather to warrant amendments to landing site regulations in regards to other issues that may arise in poor weather.

Most current regulations apply solely to the safety of those on the ground. A large open space is required so that bystanders are not struck or impeded by the descending helicopter. Other specifications are put in place with regards to maintaining clearance around the helicopter's blades as to avoid collisions. There are improvement options in regards to providing additional awareness for pilots with regards to environmental conditions. Possible areas include wind speed and direction, landing surface type, and more diverse lighting. With knowledge in additional areas, pilots will be able to make more informed decisions during descent.

An improvement in pilots' situational awareness is the best area for possible increase of safety. With the cause of so many accidents being attributed to pilot error, there are many targetable problems. With human error factor's many subdivisions, the targetable problems also span a broad spectrum in terms of cost and effectiveness.

A few combatable concerns fall under pilots' mental and emotional state and connection with the patient in the medical bay. If a pilot feels they are transporting a more critically injured patient, they may be more likely to make risky decisions that may further endanger the lives of the patient and crew. Because of the cabin layout, it is all too easy for a pilot to be aware of the patients' condition. Additionally, a pilot's physical awareness may be decreased with increased mission time and time in the air.

Other situational awareness issues relating to pilot error or miscommunication are tied into equipment use and training with said equipment. As denoted in Table 15, instrument hours are not significantly higher for HEMS pilots versus that of all helicopter pilots. As HEMS operations are much more likely to occur during inclement weather conditions, the difference should be much higher.

Table 14 - Pilot Experience Prior to Accident or Incident

	EMS		**All Helicopter**	
	Average	**Range**	**Average**	**Range**
Total Hours	6307	3000-19275	6424	29-34886
Helicopter Hours	5010	27-17380	4230	8-25000
Hours in Make	753	16-3620	1273	25-8918
Instrument Hours	269	0-1647	203	0-3613
Prior 24 Hours	1.47	0-6	3	0-15

Other issues are more minor and can be combated through simpler, but not hassle free tactics. These include general pilot fatigue, non-adherence to flight regulations regarding ceilings and flight ranges, and inability to recognize a problematic situation.

Procedural problems that arise from inattention to detail during checklists and inadequate inspections are difficult to pinpoint. Unfortunately, not much can be said in regards to inspections, and simply requiring inspections more thorough and more often will have to be enough. Advancements can be made in the areas of providing pilots information regarding weather conditions, landing site details, and general condition of the patient.

Section 3.3.2 Possible Solutions

For the mentioned problem areas, there are a few solutions to administer to the issues. Most hardware issues are fixed by installation and upgrades to existing equipment. Pilot situational awareness can come by pilot isolation and providing alternative ways of obtaining information. Implementing additional requirements in regards to inspections and checklists can combat maintenance issues.

Ideally, all HEMS vehicles would have TAWS/GWPS installed that didn't already have an approved system in place. Unfortunately, these systems are costly and requiring installation on all legacy vehicles would be problematic. In tandem with night vision goggles however, lies a similar, but more cost effective issue. Night vision goggles are significantly cheaper than an adequate TAWS/GWPS and requiring the use of night vision goggles during night operations could be an option. Even the highest of high-end night vision goggles are not as expensive as a solid TAWS. Requiring night vision goggles could be a simpler alternative to installing TAWS on legacy vehicles. They are also easily transferrable between vehicles due to their portable nature.

With current landing site regulations, pilots are not given much information aside from what they can ascertain by visual inspection. It is possible for ground crews to provide information without much extra work on their part. Something as simple as a windsock can be incredibly helpful for pilots. Marking of ground obstacles should also be taken into consideration.

Pilots' situational awareness in terms of the patients' condition is a difficult problem to combat. While it is important that a pilot is aware of a patient is in more crucial condition, it is just as important that a pilot does not get emotionally attached to the patient. This can lead to risky decision making because the pilot feels additional need to help the patient. With current helicopter layouts, the medical workspace is open to the pilots cabin in smaller vehicles, as shown in Figure 21. One possible fix may be to introduce a shroud between the pilot and patient. A simple curtain would still provide the EMS workers access to the pilots, while providing a bit of emotional distance between the pilot and patient. A curtain would not even impede operations as HEMS crewmembers can still relay important information.

Figure 22 - Helicopter interior showing opening between patient bay and cockpit.

In addition to, or alternatively, a system can be put into place similar to one used in ground ambulances. Ground EMS uses a number of different code systems as shorthand for relaying urgency, and patient condition, similar to that of police dispatch codes. The most common response codes are listed below in Table 14. These codes are for travel conditions regarding ground ambulances and provide a simple way for ambulances to translate how urgent a specific call is. These codes work in ascending order with Code 1 being the least urgent and

Code 0 being the most urgent, with codes in the middle being mixed in for certain situations [68].

Table 11 - Common emergency service response codes

CODE 1	Non-emergency response. No lights or siren.
CODE 2	Non-emergency response. Lights or siren to avoid stopped or slow traffic.
CODE 3	Life-threatening response. Active use of lights and siren.
CODE 4	All clear.
CODE 5	Area under surveillance.
CODE 6	Request for additional unit(s).
CODE 7	Lunch break.
CODE 8	Confidential information.
CODE 9	All non-emergency traffic to refrain from radio use.
CODE 0	Large emergency. All units to respond.

In addition, codes are used by some organizations to reference patient condition. “Priority 0” through “Priority 3” is used with “Priority 3” being non-emergency and “Priority 0” being dead on arrival. Strangely enough, this system is opposite the response codes with the higher priority relating to less critical situations.

A similar system could be put into place for HEMS, or a simple translation of the existing system would work as well. A translation would interface seamlessly with existing infrastructure. This system could also be modified for use with personnel on the ground.

Section 3.3.3 Proposed Viable Options

For the aforementioned targetable problems, there are a few solutions that stand out as easy to adapt and integrate, the most favorable of which being the code system similar to that of ground ambulances. This system is already in existence, and porting it to helicopter operations would be a simple option of eliminating unused codes and modifying others. Shown below in Table 15 is a possible set of codes that could be used by HEMS units.

Table 15 - Modified Emergency Response Codes

CODE 1	Non-emergency response. Passive level of emergency.
CODE 2	Non-emergency response. Active level of emergency. Mild sacrifice of fuel consumption for speed.
CODE 3	Life-threatening response. Active level of emergency. Major sacrifice of fuel consumption for speed.
CODE 4	Landing site all clear.
CODE 5	Landing site under surveillance.
CODE 6	Request for additional unit(s).
CODE 7	Confidential information.
CODE 8	All non-emergency traffic to refrain from radio use.
CODE 9	Large emergency. All units to respond.
CODE 0	Fuel consumption critical. Returning to base of operations.

This code system could be distributed relatively easily to emergency medical crews and could increase HEMS efficiency in operations. The patient condition codes could be easily migrated as well providing information to the pilots without forcing an emotional connection.

In the same vein, the curtain between the medical bay and the cockpit would also be a simplistic and cheap addition that decreases pilot distractions. A curtain costs next to nothing, even when spread over the entire country's fleet of emergency helicopters. The curtain even has the added benefit of a bit of privacy for patients in less critical condition that find themselves slightly uncomfortable.

While extremely effective, TAWS/GWPS and night vision goggles have been determined to be just too costly. To outfit all future produced helicopters and retrofit all legacy helicopters with TAWS would be an extremely costly, and time consuming endeavor. Installation of TAWS is not a simple plug and go process and requires taking a helicopter out of commission for a short period while the system is installed. Night vision goggles would be a lesser investment, but even less current helicopters have night vision goggles than have TAWS. Extra care and time would be required for being assured that goggles would be properly installed in all vehicles.

Chapter 4. Conclusion

Helicopter emergency medical services are an integral part of the medical response system. Used in extreme emergencies, treacherous terrain, and long distance patient transport HEMS operations must be stable, efficient, and effective in regards to all aspects of the process. The objective of this project was to study, investigate, and understand past and present HEMS techniques, expenses, and regulations and work to improve the infrastructure with considerations for costs, procedures, and safety.

The costs associated with operating a helicopter ambulance are exceedingly large for operating hospitals to sustain. The expenses therefore must be reduced, and cost-inducing elements of the helicopter project must be identified and reduced in a fashion that is possible for hospitals to implement. The largest and most impacting elements of the helicopter cost can be narrowed to fuel costs, aircraft lease, vehicle maintenance, and insurance premiums. All elements combined, the current cost for a hospital to operate a modern helicopter such as the Sikorsky S-76C++ may approach or exceed $2 million annually. These expenses have an opportunity cost for the hospital of losing funding for other items such as new equipment or a larger staff while providing a slim theoretical benefit to cost ratio.

The elements of operational cost that may be most easily influenced by the hospital are fuel cost and insurance premiums. A modern American Eurocopter EC135 helicopter has a fuel tank that at current prices may cost around $1600 to fill at certain airports. In order to reduce this cost, it may be possible to purchase fuel from another, cheaper airport (such as shipping fuel from Springfield, MA to Boston, MA where the fuel prices are twice that of Springfield). These savings must be weighed against the cost of hiring a shipping company to move the fuel, however. In order to reduce insurance premiums, the risk for the insurance company must be reduced in the way of improved safety on the helicopter. By implementing additional safety instruments and measures for pilots, crash rates may be positively influenced, possibly reducing insurance premiums.

Hospitals must look at emerging and future technologies for solutions that provide a larger margin of savings. Such technologies include an electric helicopter, which could operate for significantly less costs than the combustion engine helicopter while producing less noise and being more environmentally friendly. Other future technologies of interest also include better maintenance methods, so that helicopter components may be maintained longer before they must be replaced, limiting costs further.

The overall goal is to improve the total care a patient who needs the assistance of HEMS. In order to increase the patient's odds of survival, it is important to get to the patient as efficiently as possible. As discussed in Section 3.2, two ways of improving HEMS are to increase the number of designated landing sites and decrease the transportation time.

Landing zones have several regulations that must be followed to ensure the safety of not only the patients, but also the crew of the aircraft, the ground personnel, and any pedestrians around the site. It is important that all obstacles that can contribute to potential incidents during the takeoff and landing of the helicopter are as far as possible from the site. Due to the impracticality of attempting to remove all environment obstacles that can disturb a potential landing zone, the solution of creating designated landing sites will allow for a guaranteed location for the helicopter to land. This would prevent towers, electrical lines, and trees from being implemented around the zone, which would increase the probability of safe landings. By creating a structure of landing bases and sites HEMS can reach more Americans, ensuring a quicker way to receive necessary care.

The possible solutions also include using existing technology to aide in the creation of landing sites, not only in a rural setting, but also in an urban population as well. The use of timing barricades, currently used at railways, or vertical lift bridges can not only increase the number of acceptable landing zones, but also help decrease the overall transportation time of the patients. By decreasing the transportation time, critical patients can receive the care needed in order to improve their survival. If these two elements of the HEMS operation are improved upon, then we can ensure more Americans have access to this life-saving practice.

During the late 1990s and early 2000s there was an unacceptable rise in HEMS incidents and accidents. This brought into question the stability of HEMS operations with regards to aircraft maintenance, pilot fidelity, and availability of environmental information. Investigations determined numerous aspects of HEMS operations that needed revision, updates, or reinvention.

Issues found span many areas with the majority falling under one of the umbrellas of human error and decision-making, mechanical malfunction or failure, or improper or inadequate environmental information. Human error factors are attributed largely to poor decision-making. Errors made during positioning, cruise, and takeoff and landing are found to be the most troublesome, leading to controlled flight into terrain [CFIT/T] and controlled flight into obstacle [CFIT/OBS]. These issues stem from many places, many relating to the fact that pilots, in-flight medical technicians, and ground crews are all in fact human, and therefore suffer from appropriate drawbacks. Distractions, exhaustion, confusion, and inattentiveness are all present and dangerous hazards that need to be combatted.

Mechanical failure, inadequate equipment, and poor environmental conditions and information are found to be lesser contributors to accidents and incidents as compared to human error, but problems are still presented that can be administered. Issues stem from poor inspections, improperly installed or utilized equipment, inadequate methods for obtaining environmental data, and failure to enforce and adhere to regulations regarding poor weather conditions.

With human error factors being involved in a high percentage of accidents and incidents, and spanning a broad spectrum of human deficiencies, many solutions are available. Consideration should be given towards improvement of equipment and methods of transferring environmental data as well. Isolation of the pilot from distractions and emotion connection to the patients, installation of terrain awareness and warning systems [TAWS], ground proximity warning systems [GPWS], and night vision goggles are all forerunners. With some issues more apparent, less safe, and more easily combatable, the safety of HEMS pilots, EMS crews, and patients can improve with changes large and small, leading to fewer accidents and incidents.

References

1. 105 CMR 170.000: Emergency Medical Services System. 6 November 2010. Mass.gov. 12 November 2012.
2. 2012 New England and Rhode Island Ambulance Fee Schedule. 21 October 2012. NHIC, Corp. 29 November 2012.
3. About Us. 2012. Boston Med Flight. 13 November 2012.
4. Acute and Transitional Inpatient Care Administrative Days. 2012. California Department of Health Care Services.
5. Air Methods 2011 Annual Report. 29 February 2012. 8 November 2012.
6. Aircraft Insurance Quote. 2008. Leading Edge Aviation. 8 November 2012.
7. Aircraft Requirements. December 2011. 12 December 2012.
8. Airwolf Aerospace - Leaders in Aviation Value. 2012. 2012 November 2012.
9. Amendment No. 91-263; 121-273; 135-75. March 23 2000. 12 January 2013.
10. American Technologies Network Corporation. 2013. 8 March 2013.
11. Arlton, Paul. Rotor System for Helicopters. 16 August 2005. 13 December 2012.
12. Askue, Vaughan. Reducing Operating Costs. 2003. Science Direct. 11 October 2012.
13. Berglund, Birgitta, Thomas Lindvall and H Dietrich Schwela. "Guidelines for Community Noise."
14. Berkshire Health Systems 2011 Annual Report. 2011. Berkshire Health Systems. 02 November 2012.
15. Black Hawk. US Army Fact Files. 11 October 2012.
16. Blumen, Ira J. A Safety Review and Risk Assessment in Air Medical Transport. November 2002. Air Medical Physicial Association. 2012 September 2012.
17. Boston MedFlight Vehicles. 2012. September 2012 2012.
18. Bouquet, Albert, Scott Shappell and Doug Wiegmann. Human Error Associated with Air Medical Transport Accidents in the United States. 2012. 13 November 2012.
19. Busch-Vishniac, Ilene J, et al. Noise Levels in Johns Hopkins Hospital. 2005 September 2005. 20 October 2012.
20. Careless, James. Helicopter EMS: Part 3 - Solutions for Improving HEMS Safety. 30 November 2010. Cygnus Business Media. 13 November 2012.

21. Helicopter EMS: Part 3--Solutions for Improving HEMS Safety. 30 November 2010. 7 March 2013.

22. Chen, M.D., Pauline W. The Clatter of the Hospital Room. 2 August 2012. 25 November 2012.

23. "Clinical Alarms." A Siren Call to Action Priority Issues from the Medical Device Alarms Summit. 2011.

24. Danielson, Kyle. Improving Trauma Care in British Columbia Using Early Activation of Helicopter Emergency Medical Services. 2009. Simon Fraser University. 16 November 2012.

25. DESIGN: SynchroLite - Rotor - Hub - 2-blade Teetering - Tension Torsion Strap. 24 January 2009. Unicopter. 16i November 2012.

26. EC 145 Specifications. 2012. American Eurocopter Corporation. 2 December 2012.

27. EC135 Specifications. 2012. American Eurocopter Corporation. 2 December 2012.

28. ECO-Star Helicopters A Star Helicopters Maverick Compares Helicopters. 2011. Maverick Aviation Group. 16 November 2012.

29. Electronic Code of Federal Regulations Title 14: Aeronatutics and Space. 36 Noise Requirements for Helicopters Under Subpart H. 2 June 2004. US Government Printing Office. 12 November 2012.

30. Electronic Code of Federal Regulations Title 14: Aeronautics and Space. 135.25 Aircraft Requirements. 19 March 1997. US Government Printing Office. 12 November 2012.

31. Electronic Code of Federal Regulations Title 14: Aeronautics and Space. 91.409 Inspections. 27 July 2004. US Government Printing Office. 2012 November 2012.

32. Emergency Medical Services Pre-Hospital Treatment Protocols. 2012 March 2012. Mass.gov. 13 November 2012.

33. EMS Night Vision Goggles: FAA Incompetence Exposed. 3 December 2012.

34. EMT Salary | Glassdoor. 2012. 4 November 2012.

35. Eurocopter - France. 2009. aircraftcompare.com. 27 November 2012.

36. Eurocopter: EC145. 11 October 2012.

37. Flaherty, Mary and Jenna Johnson. FAA Proposes Safety Guidelines fo Emergency Medical Copters. 8 October 2010. Washington Post. 23 September 2012.

38. Fuentes, Alfonso. Chapter 18: Face-Gear Drives. 2012. GlobalSpec. 13 November 2012.

39. General Laws. 2012. Commonwealth of Massachusetts. 8 December 2012.

40. Grant, Casey C and Brian Merrifield. Analysis of Ambulance Crash Data. September 2011. 16 October 2012.

41. Helicopter Emergency Medical Service Industry Profile. April 2009. Aerosafe Risk Management. 15 November 2012.

42. Helicopter Mechanic Salary in United States. 2012. 4 November 2012.

43. HEMS Tool. 2012. UCAR. 13 November 2012.

44. Hiesterman, Ward. A Cost Effectiveness Analysis of National Helicotper Contract Practices. February 2012. 13 November 2012.

45. Improving Safety in Helicopter Emergency Services (HEMS) Operations. August 2005. 23 September 2012.

46. Inspections. 22 December 2011. 12 October 2012.

47. Landing Zone Safety. 2012. Aviation Supplies & Academics. 13 November 2012.

48. Leoni, Ray. S-70A (UH-60M Black Hawk HH-60M). November 2011. 12 October 2012.

49. Levin, Alan. Report IDs Air-Ambulance Problems. 21 April 2009. 23 September 2012.

50. Life Flight. 2012 September 2012.

51. LIFE STAR Air Medical Transportation. 2012 September 2012.

52. LifeFlight. January 2012. 23 September 2012.

53. LifeFlight 2011 Annual Report. 12 September 2012.

54. LifeFlight of Maine. 30 September 2012.

55. Local Fuel Prices. 4 November 2012.

56. Modeling Optimal Location fo Pre-Hospital Helicopter Emergency Medical Services. 2012. BioMed Central. 15 November 2012.

57. "NFPA 1600." Standard on Disaster/Emergency Management and Business Continuity Programs, 2010.

58. "NFPA Standards Directory." 2011.

59. "Noise Sources and Their Effects." n.d.

60. North East Air Alliance. 30 September 2012.

61. Novacek, Paul. Terrain Awareness and Warning Systems - TAWS. 11 October 2012.

62. Office of Emergency Medical Services Administrative Requirements Manual A/R 5-401. 1 March 2000. 11 November 2012.

63. Our Program. 30 September 2012.

64. Portage County Emergency Sevices Protocol for Summoning Helicopter. April 2010. City of Stevens Point. 15 November 2012.

65. Poulos, Christopher J, et al. Determind Level of Care Appropriatemness in the Patient Journey from Acute Care to Rehabilitation. 31 October 2011. US National Library of Medicine. 13 November 2012.

66. Private Medically Equipped Air Ambulance. 2012. EMSC. 13 November 2012.

67. Public Hearing Helicopter Emergency Medical Services. 6 February 2009. 15 November 2012.

68. Response Codes. 12 February 2013.

69. Rogers, Diane. Shhhh: Stanford Hospital Team Works to Keep Things Quiet in Patient Units. 27 May 2009. 13 November 2012.

70. S-76 Technical Information. February 2007. 14 November 2012.

71. Section 2. Special Operations. 26 July 2012. Federal Aviation Administration. 15 November 2012.

72. Sikorsky - United States. 2009. aircraftcompare.com. 27 November 2012.

73. Silverman, R A, et al. The Vertical Response Time Barries to Ambulance Response in an Urban Area. 9th Edition. Vol. 14. John Wiley & Sons, 2007.

74. Sprinter Passenger Van 2500 High Roof 144 WB Specifications. 2012. Mercedes-Benz USA, LLC. 29 November 2012.

75. Sumwalt, Robert L. Current Issues with Air Medical Transportation: EMS Helicopter Safety. 4 May 2011. 23 September 2012.

76. Toupin, Melissa. UMass Memorial Adds New Chopper. 24 August 2011. 30 September 2012.

77. Traning Bulletin No. 53 Air Ambulance. 2009. 22 September 2012.

78. UH-60M Black Hawk Helicopter. 2012 October 2012.

79. UMass Memorial LifeFlight - UMass Memorial EMS. 2012. UMass Memorial Memorial Medical Center EMS. 13 November 2012.

80. United States Department of Defense FIscal Year 2012 Budget Request. February 2011. 9 October 2012.

81. Veillette, Ph.D., Patrick R. Human Error Cited as Major Cause of US Commercial EMS Helicopter Accidents. 2001. 9]1 October 2012.

Appendices

Appendix I Typical HEMS Equipment List

Item	Class I	Class II	Class IV	Class V
Ambulance Cots	x	x		
Bag Valve Mask Ventilation Unit	x	x	x	x
Portable Oxygen Unit	x	x	x	x
Installed Oxygen System	x	x		
Installed Suction	x	x		
Portable Suction Unit	x	x	x	x
First Aid Kits	x	x	x	x
Traction Splints	x	x		
Padded Board Splints	x	x	x	x
Spine Boards and Accessories	x	x	x	x
Stair Chair	x	x		
Auxiliary Stretcher	x	x		
Transfer Sheet	x	x		
Airways	x	x		
Small Dressings	x	x		
Medium Dressings	x	x		
Large Dressings	x	x		
Soft Roller Bandage	x	x		
Triangular Bandage	x	x		
Adhesive Tape	x	x		
Bandage Shears	x	x		
Burn Sheets	x	x	x	x
Obstetrical Kit	x	x	x	x
Poison Antidote Kit	x	x	x	x
Irrigation Fluid	x	x		
Aluminum Foil	x	x		
Polyethylene Film	x	x		
Bed Pan	x	x		
Motion Sickness	x	x	x	
Pillows	x	x	x	x
Sheets	x	x	x	x
Blankets	x	x	x	x
Towels	x	x		
Tissues	x	x		
Drinking Cups	x	x	x	x
Cold Packs	x	x		

Glucose	x	x		
Infection Control Kit	x	x	x	x
Ring Cutter	x	x		
Adult Sphygmomanometer	x			
Large Adult Sphygmomanometer	x	x	x	x
Child Size Sphygmomanometer	x	x		x
Infant Sphygmomanometer	x	x	x	x
Stethoscope				
Plastic Bags	x	x		
Contaminated Trash Container	x	x	x	x
Eye Shields	x	x		
Gloves	x	x		
Hand Cleaner	x	x		x
Latex-Free Equipment	x	x	x	x
CPR Board	x	x		
Automatic Defibrillator	x	x		x
Epi-Pens	x	x	x	x
Aspirin	x	x	x	x

Appendix II Takeoff, Flyover, and Approach Profiles

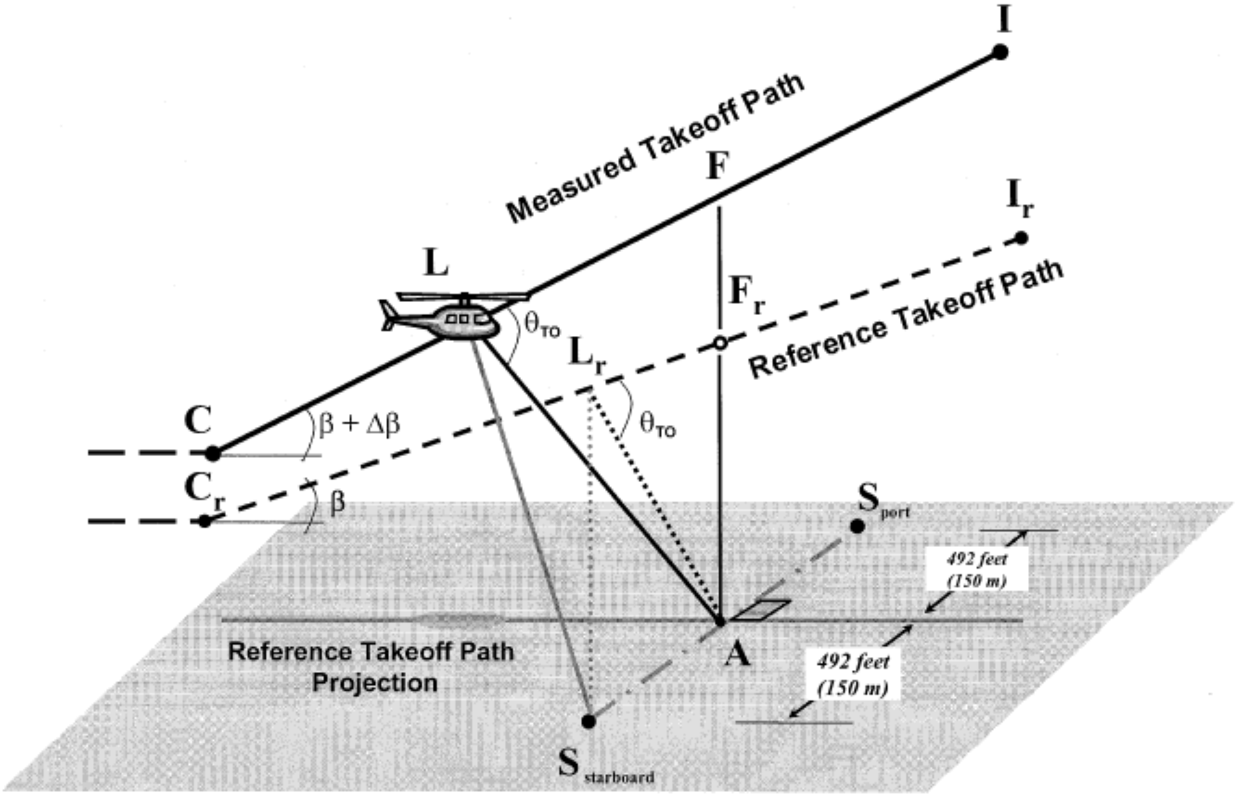


Figure H1.
Comparison of Measured and Reference Takeoff Profiles

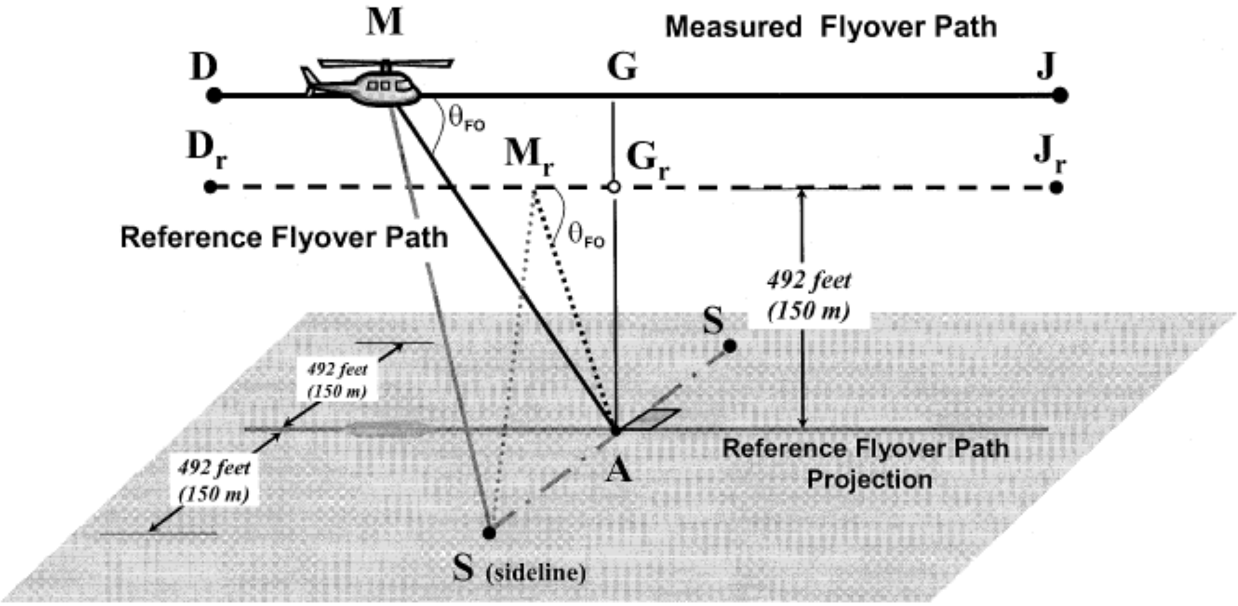


Figure H2.
Comparison of Measured and Reference Flyover Profiles

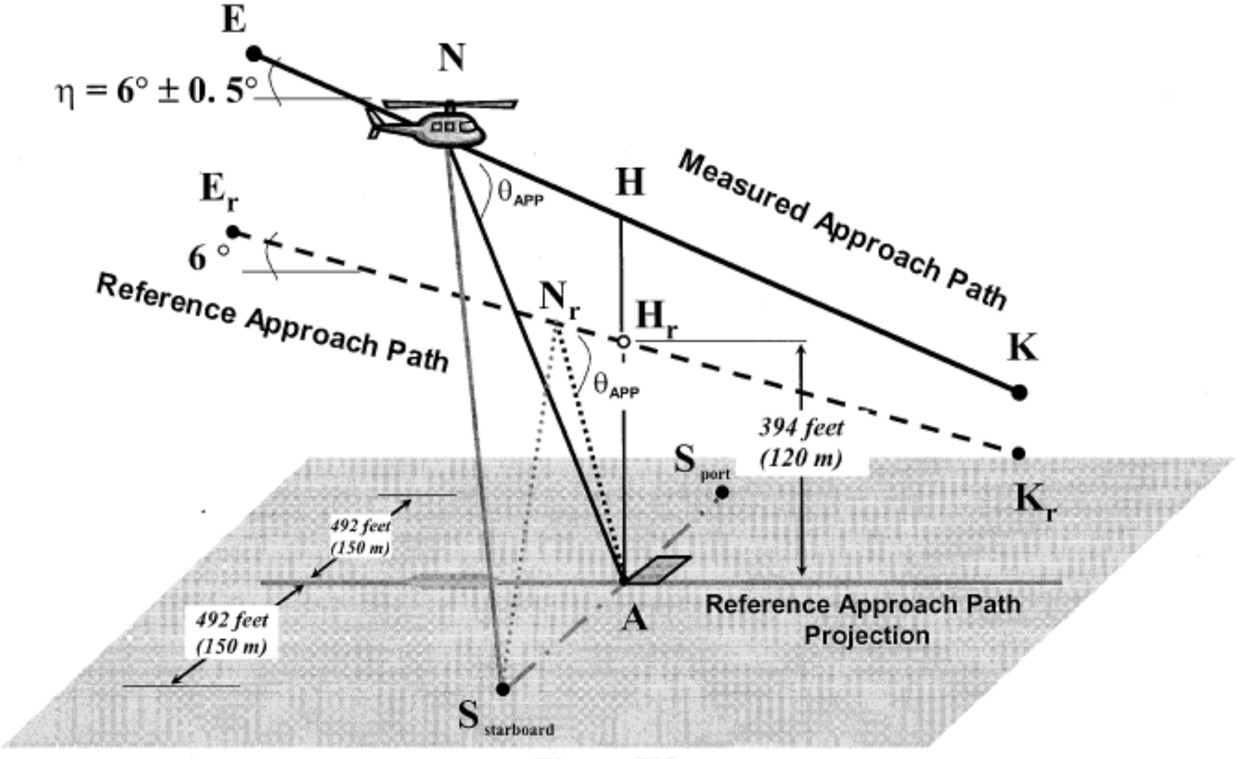


Figure H3.
Comparison of Measured and Reference Approach Profiles

Appendix III HEMS Operational Costs Worksheet

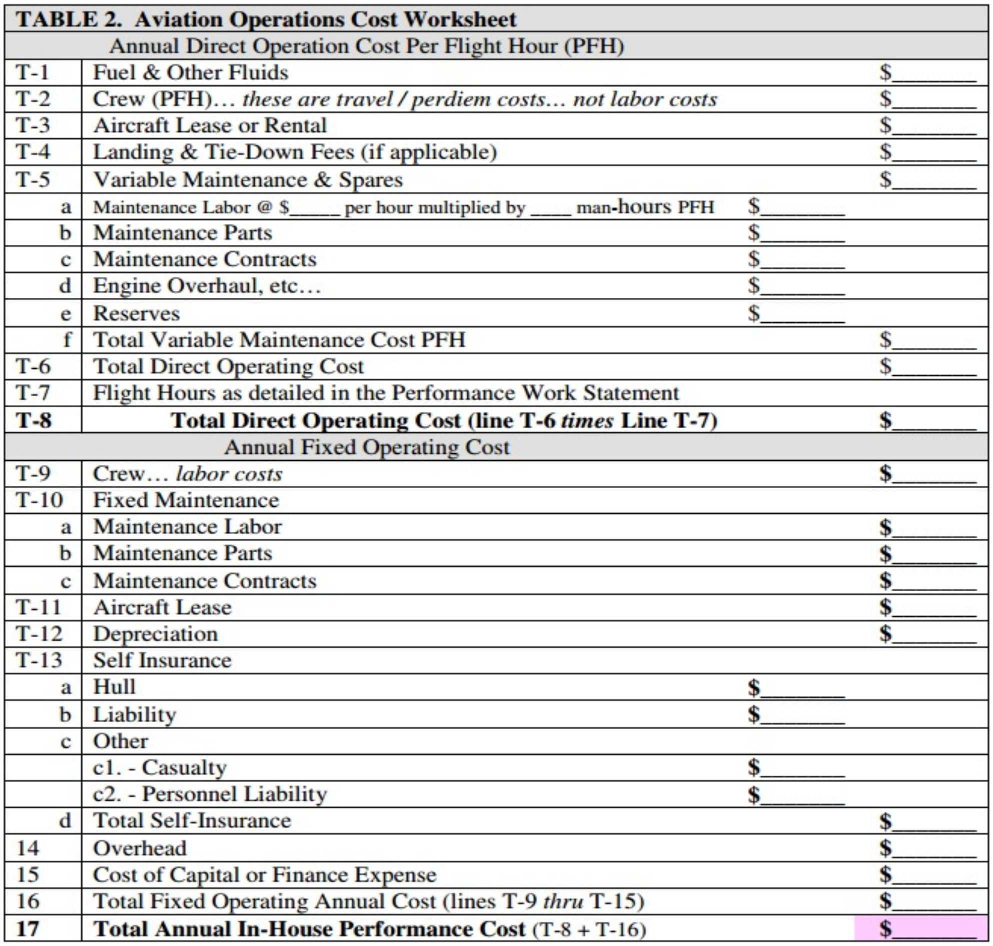


TABLE 2. Aviation Operations Cost Worksheet			
Annual Direct Operation Cost Per Flight Hour (PFH)			
T-1	Fuel & Other Fluids		$_______
T-2	Crew (PFH)… *these are travel / perdiem costs… not labor costs*		$_______
T-3	Aircraft Lease or Rental		$_______
T-4	Landing & Tie-Down Fees (if applicable)		$_______
T-5	Variable Maintenance & Spares		$_______
a	Maintenance Labor @ $_____ per hour multiplied by ____ man-hours PFH	$_______	
b	Maintenance Parts	$_______	
c	Maintenance Contracts	$_______	
d	Engine Overhaul, etc…	$_______	
e	Reserves	$_______	
f	Total Variable Maintenance Cost PFH		$_______
T-6	Total Direct Operating Cost		$_______
T-7	Flight Hours as detailed in the Performance Work Statement		
T-8	**Total Direct Operating Cost (line T-6 *times* Line T-7)**		**$**_______
Annual Fixed Operating Cost			
T-9	Crew… *labor costs*		**$**_______
T-10	Fixed Maintenance		
a	Maintenance Labor		**$**_______
b	Maintenance Parts		**$**_______
c	Maintenance Contracts		**$**_______
T-11	Aircraft Lease		**$**_______
T-12	Depreciation		**$**_______
T-13	Self Insurance		
a	Hull	**$**_______	
b	Liability	**$**_______	
c	Other		
	c1. - Casualty	**$**_______	
	c2. - Personnel Liability	**$**_______	
d	Total Self-Insurance		**$**_______
14	Overhead		**$**_______
15	Cost of Capital or Finance Expense		**$**_______
16	Total Fixed Operating Annual Cost (lines T-9 *thru* T-15)		**$**_______
17	**Total Annual In-House Performance Cost** (T-8 + T-16)		**$**_______

Appendix IV HEMS Accident Summary 1987-2000

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>Jan. 8, 1987</td><td>Pollockville, North Carolina</td><td>Bell 206L-1</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">In night visual meteorological conditions (VMC), the pilot told air traffic control (ATC) that the helicopter was level at 3,000 feet, then said that he was going to conduct an emergency landing. The flight nurse said on the hospital radio frequency that the helicopter was on fire and was going down. Radar contact and radio contact were lost, and the helicopter struck terrain in a nose-down right bank and burned. An investigation revealed a high-velocity impact with little forward movement or no forward movement. The source of the in-flight fire was not determined.</td></tr>
<tr><td>Feb. 6, 1987</td><td>Sioux Falls, South Dakota</td><td>Agusta A109</td><td>none</td><td>2 uninjured</td></tr>
<tr><td colspan="5">While in cruise flight in night VMC, excessive oil temperature was observed on one engine of the twin-engine helicopter. The pilot shut down the engine and returned the helicopter to the airport. A defective thermal relief valve was found.</td></tr>
<tr><td>April 27, 1987</td><td>Pittsburgh, Pennsylvania</td><td>Bolkow BO 105S</td><td>none</td><td>1 uninjured</td></tr>
<tr><td colspan="5">While the helicopter was being repositioned in night VMC, the magnetic chip-detector light illuminated. The pilot conducted a precautionary landing. Maintenance technicians found one metal sliver on the detector. There was no engine damage.</td></tr>
<tr><td>May 15, 1987</td><td>Phoenix, Arizona</td><td>MBB BK 117A-3</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">While the pilot shut down the helicopter engine in day VMC, another helicopter flew overhead. The other helicopter's downwash caused the accident helicopter's main rotors to strike the vertical fins.</td></tr>
<tr><td>May 30, 1987</td><td>Austin, Texas</td><td>Bell 206L-3</td><td>none</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The helicopter's engine temperature exceeded limits, and the pilot conducted a successful autorotation in day VMC. The report said that the fuel control had malfunctioned.</td></tr>
<tr><td>June 5, 1987</td><td>Choteau, Montana</td><td>Bell 206L-1</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">The helicopter struck terrain while being flown to Great Falls, Montana, in day VMC. A videotape recovered from the wreckage showed that, while being flown at treetop level up a 7,000-foot mountain slope, the helicopter suddenly yawed to the right. The helicopter was being flown at a high gross weight, at a high density altitude and with a tail wind.</td></tr>
<tr><td>June 7, 1987</td><td>Bay City, Michigan</td><td>MBB BO 105 CBS</td><td>destroyed</td><td>2 fatal, 1 minor</td></tr>
<tr><td colspan="5">The pilot attempted a steep downwind turn at low altitude in day VMC. Reported winds were 250 degrees at 18 knots, with gusts to 23 knots. An investigation showed that the right skid and main-rotor blades contacted the ground during the turn, causing loss of control.</td></tr>
<tr><td>July 8, 1987</td><td>Cupertino, California</td><td>MBB BK 117A-3</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The helicopter struck wires on final approach in night VMC to an asphalt road near a traffic accident. The report said that the pilot had not seen the wires and had not realized that there had been a collision until ground personnel told him. The pilot had made numerous orbits before beginning his descent for landing and said that his vision was hampered by blowing dust from rotor wash and a spotlight on a law-enforcement vehicle.</td></tr>
<tr><td>July 22, 1987</td><td>Louisville, Colorado</td><td>Aerospatiale SA 315</td><td>minor</td><td>1 uninjured</td></tr>
<tr><td colspan="5">The pilot was landing the helicopter in night VMC at the scene of an accident and trying to avoid contact with a car. As the helicopter engine was being shut down, the rotor struck a road sign.</td></tr>
<tr><td>Sept. 1, 1987</td><td>Charleston, West Virginia</td><td>MBB BK 117A-3</td><td>none</td><td>5 uninjured</td></tr>
<tr><td colspan="5">During cruise flight in night VMC, the no. 2 engine revolutions per minute (rpm) declined, and a low-power light illuminated. The pilot conducted a safe landing. An inspection found that the indicator was improperly connected.</td></tr>
<tr><td>Dec. 10, 1987</td><td>Little Rock, Arkansas</td><td>Bell 206L-3</td><td>destroyed</td><td>2 minor</td></tr>
<tr><td colspan="5">The helicopter was consumed by fire while parked at a heliport after a medevac (medical evacuation) flight. The on-board patient-oxygen pressure was low, and two respiratory therapists refilled the system, which is serviced through a rear baggage compartment accessible from outside the aircraft. The attendants indicated that, after the connection was made and the valve was partially opened, a fire erupted near the connection. One therapist remembered that there was oil above the baggage door.</td></tr>
<tr><td>Dec. 24, 1987</td><td>St. Louis, Missouri</td><td>Bell 206L</td><td>none</td><td>3 uninjured</td></tr>
<tr><td colspan="5">During flight in day instrument meteorological conditions (IMC), the helicopter windscreen developed fogging. The pilot activated the windscreen defogger, but the windscreen remained fogged. A precautionary landing was performed.</td></tr>
<tr><td>April 1, 1988</td><td>Springfield, Missouri</td><td>Bell 206L-1</td><td>substantial</td><td>3 serious</td></tr>
<tr><td colspan="5">The pilot obtained a weather briefing before the night takeoff. The forecast predicted marginal visual flight rules (VFR) weather, with periods of IMC. While en route to a motor vehicle accident, the pilot flew into fog and turned on the night-scanner light, then experienced spatial disorientation and failed to maintain aircraft control. During a precautionary landing, the helicopter struck a large row of hay bales.</td></tr>
</table>

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>April 2, 1988</td><td>Silver Plume, Colorado</td><td>Aerospatiale SA 316B</td><td>substantial</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The pilot was transporting a patient over mountainous terrain when a part from the flight-control mixing unit failed because of fatigue. Without collective control, the pilot executed an emergency, run-on landing on a small road. During the landing, the nose landing gear and right strut failed.</td></tr>
<tr><td>April 9, 1988</td><td>Sioux Falls, South Dakota</td><td>Agusta A109A</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">On approach to an airport, the pilot heard a loud snap and experienced an uncommanded right yaw. The helicopter touched down on one landing wheel. The yaw continued, and the left landing gear collapsed. An investigation showed that the no. 3 hangar bearing had failed from lack of lubrication and separated the tail-rotor drive shaft at the bearing race. All hangar bearings showed evidence of lack of lubrication.</td></tr>
<tr><td>April 17, 1988</td><td>Cajon, California</td><td>Aerospatiale AS 355F</td><td>destroyed</td><td>2 fatal, 1 serious</td></tr>
<tr><td colspan="5">During a flight in IMC with a nurse and a patient aboard, the helicopter struck power lines 36 feet (11 meters) above a road. The helicopter then struck a retaining wall, clipped the tops off several trees and plunged into a 70-foot-deep (21-meter-deep) ravine. The only survivor was the patient, who was strapped into a full-body board.</td></tr>
<tr><td>May 12, 1988</td><td>Reidsville, North Carolina</td><td>Aerospatiale AS 355</td><td>substantial</td><td>4 uninjured</td></tr>
<tr><td colspan="5">During cruise in day VMC, a tail-rotor blade separated from the helicopter because of fatigue failure of the composite-material spar. The tail-rotor drive shaft then separated at the tail-rotor gearbox. The fatigue failure had developed over about 500 flight hours. Bonding separation of a spar-reinforcement pad had been noted during an overhaul inspection. The operator said in maintenance records that there had been continuous problems with balancing the tail rotor. Contrary to maintenance instructions, the tail rotor was left in service.</td></tr>
<tr><td>May 14, 1988</td><td>Montegut, Louisiana</td><td>MBB BO 105C</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The pilot was unaware that the helicopter had struck a telephone wire during takeoff in day VMC. One rotor blade was gouged.</td></tr>
<tr><td>June 18, 1988</td><td>Saint Joseph, Michigan</td><td>Aerospatiale SA 365N</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The helicopter struck a light pole during a night VMC landing in a parking lot.</td></tr>
<tr><td>Dec. 18, 1988</td><td>Linwood, Kansas</td><td>Bell 206L-1</td><td>substantial</td><td>4 minor</td></tr>
<tr><td colspan="5">The helicopter was being flown to the home base in day VMC. The pilot observed smoke on the ground and descended to make a visual inspection. The helicopter struck power lines about 60 feet (18 meters) above ground level (AGL). Autorotation was attempted, and the pilot conducted a hard landing in a shallow river.</td></tr>
<tr><td>Dec. 22, 1988</td><td>Cape Girardeau, Missouri</td><td>Bell 206L-1</td><td>destroyed</td><td>3 fatal, 1 serious</td></tr>
<tr><td colspan="5">After the helicopter departed on a VFR flight, the weather deteriorated, and the pilot was unable to land at the destination hospital. In night IMC, the pilot navigated to the airport on the instrument landing system (ILS) course to determine whether the airport lighting would help him to "let down." He said that, while flying inbound at about 300 feet AGL, he experienced flicker vertigo. The helicopter struck a power line and came to rest in a field.</td></tr>
<tr><td>Jan. 8, 1989</td><td>Park City, Utah</td><td>Bell 206B III</td><td>substantial</td><td>1 uninjured</td></tr>
<tr><td colspan="5">The pilot flew a rescue team to a mountain avalanche area in day VMC. The team deplaned, and the helicopter settled backward into loose snow. The pilot added collective pitch and attempted to hover. As the helicopter left the ground, an uncommanded right spin began. The pilot performed a hovering autorotation, and, at touchdown, the tail boom entered deep snow, and the aircraft came to rest nose-high. The pilot discovered that the tail-rotor drive shaft had broken forward of the tail-rotor gearbox because of the rapid deceleration into the snow.</td></tr>
<tr><td>Feb. 13, 1989</td><td>Tyler, Texas</td><td>MBB BK 117A-1</td><td>destroyed</td><td>3 fatal</td></tr>
<tr><td colspan="5">The aircraft struck 70-foot-tall (21-meter-tall) high-tension power lines during a night flight. Weather was IMC, with low-overcast ceilings, visibility of 0.25 mile to one mile (402 meters to 1,610 meters) and rain, fog and thunderstorms. The pilot obtained three briefings from a U.S. Federal Aviation Administration flight service station and knew of the conditions. The pilot did not comply with hospital procedures for inadvertent flight into instrument flight rules. Records did not indicate that the pilot received instrument training during his one-month employment.</td></tr>
<tr><td>March 26, 1989</td><td>Bear Valley, California</td><td>Aerospatiale AS 355F</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">During the slow-speed approach to a stolport (short-takeoff-and-landing airport) at 7,073 feet in day VMC, the helicopter began to yaw to the left. The pilot applied right pedal and lowered the nose to begin a go-around, but the yaw intensified. The pilot shut down both engines and conducted an autorotation. Before landing, loose snow was blown up, and whiteout conditions occurred. During touchdown, the helicopter pitched forward into a snow bank. A sheriff's deputy said that the wind was from the south-southwest at five knots to 10 knots.</td></tr>
<tr><td>April 9, 1989</td><td>Houston, Texas</td><td>MBB BK 117A-4</td><td>destroyed</td><td>3 serious</td></tr>
<tr><td colspan="5">The helicopter was being operated from a temporary landing zone in a parking lot. As the pilot prepared to take off in night IMC, he observed people near the landing zone and advised the dispatcher. During a vertical takeoff, the helicopter encountered turbulence. Witnesses saw the helicopter drift backward. The tail rotor struck the top of a garage, and the helicopter began an uncontrolled spin and struck terrain.</td></tr>
</table>

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>June 1, 1989</td><td>Big Timber, Montana</td><td>Bell 206L III</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">The pilot told ATC that he would be conducting approaches to the hospital in VMC for night currency. Nine minutes later, he said that he was being dispatched. He was told about terrain conditions. The helicopter lifted off quickly and was flown across a hill, then struck terrain at high speed in a slight nose-low, right bank. The pilot recently was hired; his previous job involved day VFR flights of a dissimilar helicopter in the Gulf of Mexico. His last recorded night flight was before June 1984. No record was found of area familiarization training.</td></tr>
<tr><td>July 1, 1989</td><td>Des Moines, Iowa</td><td>Bell 222U</td><td>none</td><td>5 uninjured</td></tr>
<tr><td colspan="5">En route in night VMC, the helicopter's no. 1 hydraulic system failed. The pilot diverted to Des Moines. A hydraulic line had chafed through contact with the cowling.</td></tr>
<tr><td>July 6, 1989</td><td>Chiefland, Florida</td><td>Bell 206L-1</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">In day VMC, the flight was on final approach to the designated pick-up area at about 300 feet AGL when a noise was heard from the engine section. The pilot conducted an autorotation into a field. An inspection of the turbine section revealed that it was "locked up." Disassembly of the turbine module revealed that a piece of the first-stage turbine disk had separated.</td></tr>
<tr><td>July 6, 1989</td><td>Lubbock, Texas</td><td>Aerospatiale AS 355F1</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The helicopter pilot was responding to an emergency in day VMC when the helicopter struck four power lines. The pilot conducted a forced landing.</td></tr>
<tr><td>July 24, 1989</td><td>Seattle, Washington</td><td>Agusta A109</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The helicopter settled back onto the heliport because of low-rotor rpm and struck a fence in day VMC. An inspection found damage to the tail rotor.</td></tr>
<tr><td>Aug. 27, 1989</td><td>Blanchard, Idaho</td><td>Aerospatiale AS 350D</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">The helicopter was being flown in day VMC to transport to a hospital a handcuffed prisoner with a gunshot wound. The pilot reported a problem with the patient and requested police assistance when they arrived at the hospital. The pilot transmitted an expletive, and radar contact was lost. Wreckage was found over a one-mile (1.6-kilometer) area, with evidence of an in-flight breakup and main-rotor contact with the cockpit and tail cone. An investigation found evidence of a swash plate bearing seizure, which led to the in-flight breakup.</td></tr>
<tr><td>Sept. 9, 1989</td><td>White Plains, Maryland</td><td>Bell 206B III</td><td>substantial</td><td>1 serious, 3 minor, 2 uninjured</td></tr>
<tr><td colspan="5">During a night VMC takeoff from a field that had been established to pick up a patient, the pilot flew the helicopter west across a field but climbed no higher than wires until the helicopter was about 20 feet (six meters) from the wires. Then the helicopter nosed up to a 45-degree angle, climbed over the wires and descended to the ground. The pilot was faulted for delaying his climb during a night takeoff from a confined area.</td></tr>
<tr><td>Nov. 2, 1989</td><td>St. Paul, Minnesota</td><td>Bell 206L III</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The pilot encountered stronger-than-expected head winds in night VMC. After delivering the patient, he estimated that the helicopter had 12 minutes of fuel remaining. Because the flight to the home base would take about six minutes, he decided to return without refueling. Abeam the destination, the fuel-boost-pump light illuminated. The helicopter lost power from fuel exhaustion at about 50 feet AGL, and the pilot conducted a night autorotative landing.</td></tr>
<tr><td>March 6, 1990</td><td>Benton, Alabama</td><td>MBB BO 105S</td><td>substantial</td><td>4 uninjured</td></tr>
<tr><td colspan="5">After the patient was loaded into the helicopter at a remote site, the pilot conducted a hover turn and departed in night VMC, flying back on the same route on which he had arrived. About 538 feet (164 meters) east of the takeoff site and about 40 feet AGL, the helicopter struck a wire above a highway. The wire snapped and struck the main-rotor system. The pilot landed the helicopter straight ahead. The highway patrol reported that there were no wires crossing the road.</td></tr>
<tr><td>March 23, 1990</td><td>Jackson, Mississippi</td><td>Bell 206L-3</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">During takeoff from an accident site in day VMC, the helicopter struck a wire. The helicopter then was landed safely.</td></tr>
<tr><td>Nov. 2, 1990</td><td>Knoxville, Tennessee</td><td>Bell 412</td><td>substantial</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The night VMC flight was dispatched to a site on an interstate highway to pick up a patient. The searchlight was used to inspect the landing zone for obstructions, and ground personnel inspected the area. No obstructions were observed. After landing, the pilot walked along the departure corridor with a flashlight. Shortly after takeoff, the helicopter struck four wires strung across the highway. The wires were black, and the poles were hidden by buildings and trees.</td></tr>
<tr><td>Nov. 10, 1990</td><td>Denver, Colorado</td><td>Aerospatiale SA 316</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">In day VMC, the pedal jammed when a snap ring popped off, and the pivot pin dislodged. The aircraft yawed right, and the right pedal became inoperative.</td></tr>
<tr><td>Dec. 9, 1990</td><td>Cape Girardeau, Missouri</td><td>Bell 206L-1</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The crew heard a noise after takeoff and conducted a precautionary landing in day VMC. The right engine cowling had separated from the aircraft.</td></tr>
</table>

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>Jan. 26, 1991</td><td>Sonestown, Pennsylvania</td><td>MBB BK 117B-1</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">The pilot was flying a direct course in night IMC from one hospital to another hospital. The helicopter struck terrain 80 feet (24 meters) below the crest of a hill. A witness said that there was a heavy snowstorm.</td></tr>
<tr><td>Feb. 10, 1991</td><td>Valdez, Alaska</td><td>MBB BO 105 CBS</td><td>substantial</td><td>1 minor, 3 uninjured</td></tr>
<tr><td colspan="5">About 30 minutes after takeoff, one engine lost power. The pilot conducted an emergency landing in the water. The pilot had not turned on the four fuel pumps before takeoff, as required by the aircraft flight manual.</td></tr>
<tr><td>May 30, 1991</td><td>Draper, Utah</td><td>Bell 222U</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The helicopter was landed on a road in night VMC. Emergency vehicles provided landing lights for the rescue operation. The helicopter struck a sign and damaged the tail rotor.</td></tr>
<tr><td>June 8, 1991</td><td>Houston, Texas</td><td>MBB BK 117A-4</td><td>none</td><td>3 uninjured</td></tr>
<tr><td colspan="5">After an engine bearing failed in flight in day VMC, the helicopter was landed in a field.</td></tr>
<tr><td>Oct. 28, 1991</td><td>Billings, Montana</td><td>Aerospatiale AS 355F1</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">Shortly after the flight was curtailed, the flight crew felt a shudder, which they attributed to gusty winds. A portion of the left-rear engine cowl door had separated, and the main-rotor blades were damaged. The crew previously had told company personnel of a cowl-latch problem. The manufacturer had issued a relevant service bulletin that had not been implemented on the accident aircraft.</td></tr>
<tr><td>Nov. 27, 1991</td><td>Bridgeport, California</td><td>Aerospatiale SA 316B</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">During a flight in night VMC, the pilot interrupted a normal position report, broadcast "mayday" three times and told a company dispatcher the helicopter's position. He did not explain the nature of the emergency. Witnesses said that the helicopter's fuselage rotated counter-clockwise, then the helicopter veered to the west, disappeared from sight and crashed. The tail-rotor drive shaft and drive-shaft bearing had failed for undetermined reasons.</td></tr>
<tr><td>Dec. 9, 1991</td><td>DeRuyter, New York</td><td>MBB BO 105 CBS</td><td>substantial</td><td>3 fatal</td></tr>
<tr><td colspan="5">The helicopter was cruising at 2,700 feet (700 feet AGL), when it turned right 95 degrees in 15 seconds, then entered a descending left turn of 60 degrees. The helicopter struck terrain in a skids-level, nose-down pitch attitude. The accident occurred in night IMC over an unlighted area with overcast clouds. Interviews and company correspondence revealed that the pilot had a documented problem with night flying and navigation.</td></tr>
<tr><td>Dec. 29, 1991</td><td>Bedford, Michigan</td><td>Aerospatiale AS 365</td><td>minor</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The helicopter was being landed in day, VMC at the scene of an automobile accident. Downwash from the rotor blades caused a plastic sheet to enter the rotor system and tail-rotor shroud, causing damage to the rotor blades.</td></tr>
<tr><td>March 4, 1992</td><td>Fort Grant, Arizona</td><td>Aerospatiale AS 350</td><td>destroyed</td><td>2 fatal, 1 serious</td></tr>
<tr><td colspan="5">After takeoff in day VMC, ATC told the pilot that there was "weather [on his route of flight], but the intensity is unknown." Radar service was terminated, and the crew continued the flight. The surviving crewmember said that everything got "black"; about five minutes before the accident, the pilot said that the helicopter was flying into IMC.</td></tr>
<tr><td>March 4, 1992</td><td>Arlington, Texas</td><td>Bell 222U</td><td>minor</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The hydraulic-system-failure light illuminated during a flight in day IMC. The pilot executed a precautionary low-speed run-on landing in a field. During the landing, the helicopter struck a concealed hump in the ground.</td></tr>
<tr><td>May 29, 1992</td><td>Winnsboro, South Carolina</td><td>Aerospatiale AS 350</td><td>substantial</td><td>3 serious</td></tr>
<tr><td colspan="5">The pilot said that, while en route to a roadside emergency in night VMC, he encountered ground fog and entered IMC. He said that he attempted to conduct a 180-degree turn to fly out of the fog, but the aircraft struck trees and then terrain.</td></tr>
<tr><td>June 7, 1992</td><td>Mariposa, California</td><td>Bell 222</td><td>destroyed</td><td>1 minor</td></tr>
<tr><td colspan="5">The previous flight had been terminated because of sparks from the right engine. After takeoff in day VMC for a ferry flight, the right-engine temperature increased quickly, and the pilot shut down the right engine. The helicopter descended, struck a tree, then struck terrain. Examination of the right engine revealed extensive heat damage to the gas-turbine wheel with 20 percent to 30 percent deterioration of all blades.</td></tr>
<tr><td>June 15, 1992</td><td>Fort Bragg, North Carolina</td><td>Aerospatiale AS 355F</td><td>substantial</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The pilot observed the engine-fire light and smoke in the cabin and conducted an emergency landing at a nearby airport. Inspection revealed that the oil-supply line for the bearing was blocked with carbon and that the rear bearing in the no. 3 module had failed. The engine-start fuel valve, located above the engine starter/generator, began leaking fuel because of a loss of torque on connecting bolts caused by engine vibration. Inspection showed that there had been a fire in the no. 1 engine compartment that originated near the starter/generator.</td></tr>
</table>

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>June 20, 1992</td><td>Middletown, Connecticut</td><td>MBB BK 117</td><td>destroyed</td><td>1 fatal, 3 serious</td></tr>
<tr><td colspan="5">The helicopter struck an unmarked static wire 105 feet above the ground, 0.25 mile (0.4 kilometer) south of the landing area. Witnesses said that the night was dark and fog was forming. The pilot had not made a reconnaissance flight and had not said that he had identified the landing area, which was filled with numerous emergency vehicles with red and blue flashing lights. Neither the pilot nor the hospital communication coordinator had requested hazard information about the area.</td></tr>
<tr><td>June 28, 1992</td><td>Scipio, Utah</td><td>Bell 222UT</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The helicopter encountered clear air turbulence while en route to pick up a patient. The helicopter's nose pitched up rapidly to about 20 degrees, activating the emergency locator transmitter (ELT). The pilot felt feedback through the controls and landed to reset the ELT. Later, the pilot observed mast-torque fluctuations and a zero reading on the gauge. A post-flight inspection showed that the transmission had contacted its mounts, severing several electrical leads, including the torque sensor.</td></tr>
<tr><td>Sept. 2, 1992</td><td>Bayfield, Colorado</td><td>Bell 206L-3</td><td>substantial</td><td>3 serious</td></tr>
<tr><td colspan="5">While attempting to land in day VMC in rough, rocky mountainous terrain at a pressure altitude of 9,803 feet, loss of tail-rotor effectiveness occurred, and the helicopter descended rapidly and struck rocks. The helicopter was being operated in a performance-limited portion of the hover-performance chart.</td></tr>
<tr><td>Sept. 19, 1992</td><td>Phoenix, Arizona</td><td>MBB BK 117B-1</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The aircraft began settling rapidly during landing in day VMC. The pilot noticed the N_2 (engine high-pressure rotor) unwinding. A hard landing resulted.</td></tr>
<tr><td>Dec. 11, 1992</td><td>Aguila, Arizona</td><td>MBB BK 117B-1</td><td>minor</td><td>1 uninjured</td></tr>
<tr><td colspan="5">In day VMC, a medical ambulance was driven under the helicopter to unload a patient. The helicopter rotor blade struck the antenna on the ambulance.</td></tr>
<tr><td>Jan. 31, 1993</td><td>Chino, California</td><td>Bell 412</td><td>minor</td><td>5 uninjured</td></tr>
<tr><td colspan="5">On climb-out in night VMC, the helicopter struck an electrical power line. The pilot conducted a precautionary landing, and the patients were transferred to another helicopter.</td></tr>
<tr><td>May 27, 1993</td><td>Cameron, Missouri</td><td>Aerospatiale AS 350B</td><td>destroyed</td><td>2 fatal, 2 serious</td></tr>
<tr><td colspan="5">The helicopter was en route in day VMC with a patient when the nurse heard a loud "pop," followed by a clattering and a horn alarm. The helicopter struck terrain in a field. Witnesses said that the wind was strong and gusty from the south. The engine had lost power because of failure of the labyrinth seal in the second-stage turbine-nozzle guide vane.</td></tr>
<tr><td>June 6, 1993</td><td>Saint Mary's, Pennsylvania</td><td>Aerospatiale SA 365</td><td>minor</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The helicopter began an uncontrolled turn to the left after engine start, then lifted off the platform in night VMC. The pilot returned the helicopter to the pad and shut down the engines.</td></tr>
<tr><td>June 20, 1993</td><td>West Monroe, Louisiana</td><td>Bell 206L-3</td><td>substantial</td><td>3 minor</td></tr>
<tr><td colspan="5">The helicopter struck high-tension power lines in day IMC while on initial climb from the median of an interstate highway after picking up a patient who had been in an automobile accident. The weather was reported as 500 feet overcast, with four miles (6.5 kilometers) visibility in fog and rain showers.</td></tr>
<tr><td>Nov. 19, 1993</td><td>Portland, Maine</td><td>Bell 206L-1</td><td>destroyed</td><td>3 fatal, 1 serious</td></tr>
<tr><td colspan="5">The pilot departed on a night flight with 310 pounds (141 kilograms) of fuel. He said that fuel consumption was about 200 pounds to 220 pounds (91 kilograms to 100 kilograms) per hour and that the 97-nautical mile (180-kilometer) flight normally took less than one hour. The pilot encountered IMC and a 40-knot to 60-knot head wind. As the pilot was being vectored to the airport, the engine lost power. He ditched the helicopter into rough seas seven miles (11 kilometers) east of the airport. The company operations manual says, "The minimum acceptable weather is in VFR conditions."</td></tr>
<tr><td>Feb. 1, 1994</td><td>Caro, Michigan</td><td>MBB BO 105S</td><td>minor</td><td>2 uninjured</td></tr>
<tr><td colspan="5">The hospital recently had designated part of a circular driveway area for helicopter landings; this flight was to be the first to use the new site. Before touchdown in night IMC, the pilot was told to land elsewhere. He established a hover about 10 feet AGL at the original landing site while assessing the alternate site. The rotors blew snow, which partially obscured the pilot's view, and a paramedic crewmember grabbed his arm and told him to watch out for a light pole. The pilot was distracted; the helicopter struck a light assembly, damaging the rotor blades.</td></tr>
<tr><td>March 4, 1994</td><td>Indianapolis, Indiana</td><td>MBB BK 117A-3</td><td>minor</td><td>1 uninjured</td></tr>
<tr><td colspan="5">On a positioning flight in night VMC, the helicopter lost an engine cowling after the latches opened in flight.</td></tr>
</table>

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>April 22, 1994</td><td>Bluefield, Virginia</td><td>Bell 412</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">The pilot was told to maintain 7,000 feet until established on an ILS approach in day IMC. Recorded radar data show that the helicopter did not intercept the localizer and that the last recorded position was about five miles (eight kilometers) southwest of the airport at 4,100 feet. The accident site was on a mountain 7.5 miles (12 kilometers) southwest of the airport at 3,400 feet. A witness said that the mountain was obscured by fog.</td></tr>
<tr><td>June 23, 1994</td><td>Amarillo, Texas</td><td>Aerospatiale AS 350B</td><td>minor</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The helicopter struck a wire during takeoff from a highway in day VMC. The pilot landed the helicopter immediately. Damage was found on the main rotors.</td></tr>
<tr><td>July 9, 1994</td><td>Granite, Colorado</td><td>Aerospatiale AS 350B</td><td>destroyed</td><td>2 fatal, 3 minor</td></tr>
<tr><td colspan="5">The helicopter was dispatched in day VMC to pick up an injured hiker on a 14,000-foot mountain. Terrain at the pickup point was about 12,200 feet with a 35-degree slope. Ground rescue personnel said that the pilot told them that he would place the helicopter's right skid on the mountain slope to allow them to load the patient on the downhill side. As the helicopter hovered above them, the main-rotor blades struck rocks, and the helicopter tumbled 800 feet (244 meters) down the mountain.</td></tr>
<tr><td>Aug. 9, 1994</td><td>Stateline, Nevada</td><td>Aerospatiale SA 316B</td><td>substantial</td><td>3 minor</td></tr>
<tr><td colspan="5">The helicopter was en route in dark-night VMC to pick up an auto-accident victim. The pilot terminated the approach about 200 feet AGL (7,400 feet), lowered the collective and descended vertically. A rapid rate of descent developed, which the pilot was unable to arrest, and the helicopter landed hard. Density altitude was 9,500 feet.</td></tr>
<tr><td>Aug. 19, 1994</td><td>Albert Lea, Minnesota</td><td>Bell 230</td><td>substantial</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The pilot was maneuvering the helicopter in day VMC to land on the airport ramp to pick up a patient from a waiting ambulance. To avoid overflying trees, a hangar and an untied airplane, the pilot conducted a steep approach at low airspeed while side-slipping the helicopter to maintain alignment on a track of 175 degrees. When the pilot adjusted the collective to slow the rate of descent and the rate of closure, the revolutions per minute (rpm) dropped, the helicopter made an unusual noise and the airframe shuddered. The pilot attempted to conduct a running landing to a grassy area next to the intended landing site. The helicopter landed hard and bounced twice. A fire consumed the top of the cabin. Winds were from 310 degrees at 15 knots, gusting to 20 knots.</td></tr>
<tr><td>Aug. 30, 1994</td><td>Fitchburg, Wisconsin</td><td>Bell 206L-1</td><td>minor</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The pilot continued flight into deteriorating day IMC conditions, and the helicopter struck an object.</td></tr>
<tr><td>Nov. 22, 1994</td><td>Lincoln, Nebraska</td><td>MBB BK 117</td><td>none</td><td>4 uninjured</td></tr>
<tr><td colspan="5">After the chip-detector light illuminated in flight in day VMC, the pilot landed the helicopter at the nearest airport.</td></tr>
<tr><td>Dec. 1, 1994</td><td>Ann Arbor, Michigan</td><td>Agusta A109</td><td>destroyed</td><td>3 fatal</td></tr>
<tr><td colspan="5">The helicopter had been airborne in day VMC for two minutes when the pilot requested landing permission, saying, "I'd like to proceed inbound … single-engine landing, please." He immediately canceled the request and said, "I'm going down at this time." He told the dispatcher his intended landing position and, about 25 seconds later, said that impact with terrain was imminent. Investigation revealed that neither engine was operating; no mechanical reason for the loss of engine power or the need for an engine shutdown was determined. Damage to the rotor indicated that rpm was low at the time of impact.</td></tr>
<tr><td>Dec. 13, 1994</td><td>Topeka, Kansas</td><td>Bell 206L-1</td><td>none</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The helicopter experienced rotor problems and hydraulic problems after departure in night VMC. The pilot conducted a precautionary landing in a field.</td></tr>
<tr><td>Dec. 20, 1994</td><td>Pittsburgh, Pennsylvania</td><td>Aerospatiale AS 355</td><td>none</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The pilot heard a loud bang en route in night VMC and diverted. The cargo doors had separated from the helicopter. The doors were not secured prior to flight.</td></tr>
<tr><td>March 7, 1995</td><td>Portland, Oregon</td><td>Bell 230</td><td>substantial</td><td>2 uninjured</td></tr>
<tr><td colspan="5">The pilot said that, while landing in day VMC at the hospital heliport, about three feet to four feet above touchdown, he felt an impact from the tail area and severe vibrations. He rolled both throttles off and completed a landing from a low hover. The tail rotor had struck a heliport perimeter fence. The pilot said that the fence had an approximate four-inch (10-centimeter) gap at mid-span. The tail-rotor guard had slipped into the gap, resulting in contact between the tail rotor and the fence.</td></tr>
<tr><td>April 10, 1995</td><td>Glastonbury, Connecticut</td><td>MBB MK 117A-1</td><td>none</td><td>4 uninjured</td></tr>
<tr><td colspan="5">In day VMC, while practicing confined-area landings in conjunction with flight-nurse training, the aircraft sustained a puncture in the rear fuel bladder from an unseen object. Everyone on board smelled fuel. The pilot began a shallow approach to an open field. During the approach, the flight nurse reported fuel on the back window and smoke trailing the helicopter. During the landing, the pilot observed fuel drops on the windshield. The pilot landed the helicopter and everyone on board evacuated.</td></tr>
</table>

Date	Location	Helicopter Type	Helicopter Damage	Injuries
May 31, 1995	Lost Hills, California	Eurocopter AS 355F1	substantial	3 uninjured

On a dark, moonless night in VMC, the helicopter was being flown to a sparsely populated area without ground-reference lights to pick up a patient. Fire department personnel had illuminated a landing site with two fire trucks. The pilot said that he flew over the area and began the approach from 300 feet. He said that he became spatially disoriented and lost visual reference with the ground while looking at his instruments to correct a high rate of descent and low airspeed. The helicopter pitched nose-down, but the pilot stabilized the helicopter just before touching down hard. The aircraft bounced 20 feet to 30 feet, rolled to the left and struck terrain.

June 21, 1995	Des Moines, Iowa	Bell 222UT	substantial	3 uninjured

The pilot said that after takeoff in night VMC, the helicopter yawed. The nurse and paramedic said that they heard a pop, and the no. 1 engine-out indicator light illuminated. The pilot reduced the throttle to flight idle and turned the helicopter toward the airport to land. The pilot said that the no. 1 engine-fire indicator light illuminated, and he discharged the fire-extinguisher bottle. The pilot conducted an emergency landing. The engine-air-inlet duct on the left engine had collapsed internally because of delamination.

July 12, 1995	Fordland, Missouri	Bell 206L-1	none	3 uninjured

During an emergency medical services (EMS) ferry flight in day VMC, the bendix shaft failed, causing a loss of torque. The pilot conducted an off-field landing.

Aug. 7, 1995	Montgomery, Alabama	Bell UH-1H	substantial	6 uninjured

The pilot was conducting an approach in day VMC when the main-rotor blades contacted trees.

Aug. 26, 1995	Pittsford, New York	Bell 206L-1	none	3 uninjured

The chip-detector light illuminated during the flight in day VMC, and the pilot diverted to the nearest airport. The patient was transported by ground ambulance.

Aug. 27, 1995	Oklahoma City, Oklahoma	Bell 206L-1	substantial	4 uninjured

After landing the helicopter in day VMC on the roof helipad, the pilot was told that the hospital elevator was inoperative, and the stairway would not accommodate the medical equipment. During the subsequent takeoff, the engine lost power, and the pilot began an autorotation. Below the helicopter were a full parking lot, a street and trees. The pilot said that he flared the helicopter over the trees, lowered the pitch and applied forward cyclic in an attempt to regain rpm and airspeed. The helicopter touched down in an uneven field and skidded 30 yards (27 meters). The company reported a low-side governor failure as the cause of the power loss.

Sept. 11, 1995	Winslow, Washington	Agusta A109A II	destroyed	3 fatal

Witnesses said that the helicopter was flying low over the ground, and over water in night IMC toward a nearby island. The helicopter struck the water and sank. Some witnesses said that the engines sounded normal before the accident, but others reported a popping sound from the engines.

Sept. 14, 1995	Houston, Texas	MBB BO 105C	destroyed	3 uninjured

The pilot said that, during cruise flight at 800 feet in day VMC, he heard an unusual whine from the engines and then a loud snap and felt severe vibrations. After determining that a dual engine failure had occurred, the pilot observed the no. 1 engine-fire warning light illuminate and smelled smoke. The pilot began an autorotation to a shopping mall parking lot. The helicopter touched down and slid 200 feet (61 meters) to a stop. When the nurse opened the door, smoke billowed into the cabin from the tunnel area. Examination of the helicopter revealed that the drive shaft for the left engine had separated from the transmission-input-shaft flange. Examination of the main-transmission lower housing revealed debris partially blocking the oil channel for the left side input pinion. Both engines experienced internal thermal damage and foreign object damage.

Sept. 20, 1995	Ware, Illinois	Bell 206L	substantial	2 minor, 1 uninjured

At the time of departure, the ceiling was 1,900 feet and visibility was four miles (6.4 kilometers). The destination was an automobile-accident scene 25 miles (40 kilometers) away. The pilot said that, after the night takeoff, the helicopter flew through small clouds, and he decided to terminate the flight. He initiated a left turn and encountered IMC. The pilot said that he tried to transition to instruments but that he was unable to make the transition before he lost control of the helicopter. The pilot was unable to regain control before ground impact.

Oct. 29, 1995	Tampa, Florida	MBB BO 105A	minor	2 uninjured

The helicopter was on approach to a hospital helipad in night VMC when the pilot smelled fuel. A post-flight investigation revealed that a supply-fuel-tank hose clamp had failed.

Dec. 7, 1995	Carlsbad, Texas	Aerospatiale AS 365	minor	3 uninjured

The helicopter departed in day VMC to pick up a patient involved in an accident. After landing at the scene, the tail rotor struck a mesquite tree.

Dec. 28, 1995	Chicago, Illinois	Aerospatiale AS 365	none	4 uninjured

The no. 2 engine gas-generator gauge fluctuated during flight in day VMC. The pilot declared an emergency and conducted a precautionary landing.

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>Feb. 19, 1996</td><td>Surprise, Arizona</td><td>MBB BO 105C</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">While the pilot attempted to land in night VMC to pick up an accident victim, the helicopter tail rotor struck a wire. A police officer on the ground had advised that there were no wires.</td></tr>
<tr><td>March 25, 1996</td><td>Springtown, Texas</td><td>Bell 222U</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The pilot was attempting to land the helicopter on a highway in day VMC when the main rotors struck an electrical power line.</td></tr>
<tr><td>May 14, 1996</td><td>Oklahoma City, Oklahoma</td><td>Bell 206L-1</td><td>none</td><td>1 uninjured</td></tr>
<tr><td colspan="5">The transmission chip light prompted the pilot to conduct two precautionary landings in day VMC. No foreign material was found on the plug.</td></tr>
<tr><td>June 12, 1996</td><td>Pittsburgh, Pennsylvania</td><td>MBB BK 117B-1</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The pilot was flying a shallow approach to a hospital heliport in night VMC. The pilot decreased the approach angle, and as the helicopter neared the landing pad, the pilot flared and felt the heels of the skids touch first and slide slightly. The pilot found damage to the tail stinger and vertical end plate, which had grazed a pole near the helipad.</td></tr>
<tr><td>June 13, 1996</td><td>Madison, South Dakota</td><td>Bell 206L-1</td><td>none</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The engine was replaced because of metal particles found on the chip detector. A maintenance flight check was conducted and the aircraft was returned to service. On the next flight, in day VMC, the oil fluctuated and a chip light illuminated. The pilot made a precautionary landing and shut down the engine.</td></tr>
<tr><td>June 21, 1996</td><td>Cleveland, Ohio</td><td>Sikorsky S-76</td><td>none</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The no. 2 engine failed during flight in day VMC. The pilot diverted the helicopter to the nearest airport and landed. The starter generator's drive seal was leaking.</td></tr>
<tr><td>July 28, 1996</td><td>Oceanside, California</td><td>Bell 222U</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">In day VMC, the main-rotor blades struck the upper deflector of the helicopter's wire-strike protection system.</td></tr>
<tr><td>Oct. 20, 1996</td><td>Rockwall, Texas</td><td>Bell 222U</td><td>minor</td><td>4 uninjured</td></tr>
<tr><td colspan="5">An unauthorized vehicle struck the tail stinger at an on-scene operation while the helicopter was being prepared for takeoff in day VMC.</td></tr>
<tr><td>Nov. 7, 1996</td><td>Jersey Shore, Pennsylvania</td><td>Aerospatiale SA 365</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">On approach in day VMC to an approved landing site to pick up an aeromedical patient, the right engine cowling separated from the aircraft and struck a rotor blade and the upper fenestron (a type of tail rotor). An investigation revealed a worn latch.</td></tr>
<tr><td>Nov. 13, 1996</td><td>Rock Rapids, Iowa</td><td>Bell 222U</td><td>minor</td><td>5 uninjured</td></tr>
<tr><td colspan="5">During cruise flight in night VMC at 2,500 feet, the left engine failed. The right engine would not produce sufficient power to continue flight, so an autorotation was made into a farm field.</td></tr>
<tr><td>Nov. 22, 1996</td><td>Tampa, Florida</td><td>MBB BO-105-A</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">During hover takeoff in day VMC, the no. 2 engine failed, and parts from the engine separated from the helicopter. The helicopter was landed safely. The first-stage turbine wheel had failed.</td></tr>
<tr><td>Dec. 12, 1996</td><td>Penn Yan, New York</td><td>MBB BO 105 CBS</td><td>destroyed</td><td>3 fatal</td></tr>
<tr><td colspan="5">After takeoff in night IMC from an open field, the pilot radioed the company dispatcher that the helicopter was airborne and to stand by for his report on time and distance to the destination. The distance was to be obtained from a global positioning system (GPS) receiver on the rear of the helicopter's center console. Two minutes later, the helicopter struck terrain in a secluded wooded area on rising ground about 1.1 miles (1.8 kilometers) northwest of the departure point. Witnesses said that no horizon was discernable in the night darkness. Winds were strong and gusty. The area was near rising terrain with peaks at 2,700 feet; the accident occurred at 1,740 feet, with cloud cover between 1,900 feet and 2,000 feet.</td></tr>
<tr><td>Feb. 20, 1997</td><td>Medina, Ohio</td><td>Sikorsky S-76</td><td>none</td><td>2 uninjured</td></tr>
<tr><td colspan="5">During cruise flight in day VMC, the no. 2 engine oil pressure fluctuated. The engine was slowed to flight idle, and the oil pressure continued to decrease into the yellow arc. The engine was secured, and shutdown was completed. A precautionary landing was conducted at the nearest airport.</td></tr>
<tr><td>March 5, 1997</td><td>Washington, Pennsylvania</td><td>Aerospatiale AS 355</td><td>substantial</td><td>1 minor</td></tr>
<tr><td colspan="5">The pilot conducted a test flight after a maintenance technician changed the cyclic lateral servo. After completing the flight, the pilot began a takeoff to reposition the helicopter to the hospital helipad. The helicopter was in a three-foot to four-foot hover in day VMC when it began to roll left. The pilot attempted to correct for a perceived crosswind, but the left roll continued. The helicopter struck the ground on its left side. The accident report said that the hydraulic servos apparently had undergone maintenance and did not meet manufacturer's specifications.</td></tr>
</table>

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>March 14, 1997</td><td>Lena, Louisiana</td><td>MBB BO 105S</td><td>destroyed</td><td>1 fatal, 1 serious</td></tr>
<tr><td colspan="5">During a dark-night flight, the pilot descended to 500 feet because of weather and followed a highway. The pilot slowed the helicopter to 70 knots. The medical crewmember said that he felt "a shudder, like the shudder as the helicopter decelerates through effective translational lift." He heard the pilot say an expletive and felt the helicopter turn left as he saw sparks overhead and felt Plexiglas hit him. The helicopter struck the ground. The company operations manual says that the cross-country VFR minimum ceiling at night is 1,000 feet and minimum visibility is three miles (five kilometers). The medical crewmember said that the ceiling was about 550 feet to 600 feet, and visibility was about two miles (3.2 kilometers).</td></tr>
<tr><td>April 30, 1997</td><td>Kane, Pennsylvania</td><td>MBB BK 117A-1</td><td>substantial</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The helicopter struck the ground during landing at a hospital helipad in day VMC. The windsock indicated winds of three knots to five knots from the west/southwest. Because of obstacles, the pilot descended vertically to the helipad. As the pilot attempted to stop the descent rate at 50 feet AGL, the helicopter shuddered with the application of additional power. The helicopter yawed right. Additional collective pitch did not slow the rate of descent; instead, the rate of descent increased, and the pilot said, "We're settling in, guys." At touchdown, all remaining collective pitch was applied. The pilot said that he reduced the collective to stop the yaw rate; the helicopter stopped after turning 180 degrees.</td></tr>
<tr><td>May 9, 1997</td><td>Reno, Nevada</td><td>MDD MD-900</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">During an approach in day VMC to a medical-center heliport, the pilot observed that the helicopter hovered nose-low. A post-flight inspection revealed that the adjustable collective-drive-link assembly had failed. Subsequently, a service bulletin and an airworthiness directive were issued.</td></tr>
<tr><td>June 4, 1997</td><td>Clay, New York</td><td>Bell 206L-1</td><td>minor</td><td>2 uninjured</td></tr>
<tr><td colspan="5">The helicopter cut a cable-television wire while being flown in day VMC.</td></tr>
<tr><td>Aug. 19, 1997</td><td>Florence, South Carolina</td><td>MBB BK 117A-3</td><td>minor</td><td>1 uninjured</td></tr>
<tr><td colspan="5">In day VMC, the aircraft struck a bird, which shattered the aft greenhouse after penetrating the windscreen.</td></tr>
<tr><td>Aug. 26, 1997</td><td>Hawley, Minnesota</td><td>Bell 222U</td><td>minor</td><td>2 uninjured</td></tr>
<tr><td colspan="5">The helicopter struck a wire in day VMC while on approach to an automobile-accident site. A medical crewmember shouted "wire," and the pilot initiated a go-around. The pilot did not know whether the helicopter actually struck the wire; nevertheless, he flew the helicopter back to the hospital pad.</td></tr>
<tr><td>Sept. 15, 1997</td><td>Salt Lake City, Utah</td><td>Bell 206L-3</td><td>minor</td><td>4 uninjured</td></tr>
<tr><td colspan="5">In day VMC, while the helicopter was lifting off from a helipad in a right turn, the tail rotor struck a parked ambulance. The pilot immediately returned the helicopter to the pad.</td></tr>
<tr><td>Dec. 14, 1997</td><td>Littleton, Colorado</td><td>Bell 407</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">The helicopter arrived from the northeast at the scene of an automobile accident and circled the site clockwise before landing. After a takeoff in night VMC with the patient on board, the pilot began a right turn. The helicopter struck power lines. Company landing-zone departure procedures were to climb straight ahead in a near-vertical climb to a minimum of 300 feet AGL before turning.</td></tr>
<tr><td>Jan. 11, 1998</td><td>Sandy, Utah</td><td>Bell 222UT</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">The helicopter was dispatched in night IMC to transport a skier injured in an avalanche. Snow was not falling when the helicopter departed the hospital, but there were gusty winds and snow when the helicopter arrived at the landing zone. The dispatcher telephoned the pilot to advise him that hospital weather conditions had deteriorated. A sheriff's deputy said that the helicopter took off from the landing zone in blizzard conditions and circled, then turned and disappeared from view. Seconds later, a deputy heard "a slight muffled boom." The wreckage was found on mountainous terrain.</td></tr>
<tr><td>April 25, 1998</td><td>Wellsboro, Pennsylvania</td><td>Aerospatiale SA 365</td><td>minor</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The belly panel separated from the helicopter during flight in day VMC. The panel was never found.</td></tr>
<tr><td>May 10, 1998</td><td>Jackson, Ohio</td><td>MBB BK 117A-1</td><td>minor</td><td>4 uninjured</td></tr>
<tr><td colspan="5">In night VMC, the left-side engine cover separated from the aircraft and struck the rotor blades.</td></tr>
<tr><td>May 24, 1998</td><td>Springdale, Arkansas</td><td>Bell 206L-3</td><td>substantial</td><td>3 serious</td></tr>
<tr><td colspan="5">Shortly after the helicopter lifted off in day VMC from a hospital helipad to pick up a patient, the engine lost power. The helicopter descended into a parking lot, landed hard and rolled onto its right side. Disassembly of the engine revealed that both the N_1 (low-pressure rotor) and the N_2 shafts had separated. Coke deposits were found on the inside diameter of the N_2 shaft. Metallurgical examination of the shafts determined that coke buildup consistent with reduced oil flow led to friction between the shafts. The friction produced heat that resulted in softening and failure of the shafts. The report said that maintenance personnel failed to assemble properly the engine's accessory gearbox; that failure resulted in a partial blockage of the main oil passage by an O-ring.</td></tr>
<tr><td>June 5, 1998</td><td>La Gloria, Texas</td><td>Eurocopter AS 350BA</td><td>destroyed</td><td>3 fatal</td></tr>
<tr><td colspan="5">The helicopter was being flown in dark-night IMC to pick up a traffic-accident victim. The aircraft was observed on radar at 1,800 feet, about two miles from the traffic-accident site. The helicopter struck trees while in a left turn, with a nose-low attitude. A witness said that visibility was less than one mile (1.6 kilometers) because of smoke from forest fires.</td></tr>
</table>

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>July 29, 1998</td><td>Tranquility, California</td><td>Bell 222B</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The helicopter was dispatched in night VMC to pick up two victims of an automobile accident. The pilot made three high orbits of the landing site before the approach. Before touchdown, the helicopter was engulfed in dust. While the pilot was climbing the helicopter out of the dust, the right wheel touched down, and the helicopter rolled over.</td></tr>
<tr><td>Aug. 20, 1998</td><td>Spencer, Iowa</td><td>Bell 222</td><td>destroyed</td><td>3 fatal</td></tr>
<tr><td colspan="5">The helicopter was en route in night VMC for a patient transfer. The pilot maintained 130 knots airspeed on a direct course at 2,500 feet to 3,000 feet. While in cruise descent, the aircraft experienced an in-flight break-up. Examination of the swash plate outer-ring assembly revealed that the flats of the swash plate pinheads were causing wear on the inside surface of the swash plate ring. The maintenance manual says that no wear or movement of the pin should be permitted.</td></tr>
<tr><td>Aug. 28, 1998</td><td>Topeka, Kansas</td><td>MBB BK 117</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The helicopter was being flown in day VMC to obtain engine-matching-adjustment measurements after installation of a new no. 1 engine. The pilot said that there was a severe bump when the helicopter was about two miles from the airport, followed by a bang, a yaw and violent oscillations. The helicopter rotated to the right, descended and struck terrain. An investigation showed that the no. 1 engine cowling had separated during flight, damaging the main-rotor blades and resulting in an imbalance and in the loss of the tail-rotor gear box. A service bulletin had addressed removing and modifying latches of the access doors, but the actions were not incorporated on the accident helicopter.</td></tr>
<tr><td>Nov. 29, 1998</td><td>Idaho City, Idaho</td><td>MDD MD-900</td><td>substantial</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The helicopter was dispatched in dark-night VMC to pick up a traffic-accident victim in a remote canyon. Before landing, the pilot asked ground crewmembers about wires and was told that there were none. After landing, the pilot used a flashlight to check for obstructions in the direction of takeoff. The pilot observed no obstructions except trees and then conducted a vertical takeoff because of the narrowness of the canyon. At about 150 feet, the pilot rotated the helicopter forward and at approximately 20 knots, the crew heard a loud noise and saw a bright white light. The helicopter had struck unmarked transmission lines. Because of risks in attempting to land again at the scene, the pilot completed the flight and conducted a normal landing at the hospital with the patient and crew.</td></tr>
<tr><td>Dec. 13, 1998</td><td>San Angelo, Texas</td><td>Aerospatiale AS 350BA</td><td>substantial</td><td>2 uninjured</td></tr>
<tr><td colspan="5">On the previous flight, the director of operations had conducted a check ride; the last maneuver was a hydraulics-off maneuver. On the accident flight in night VMC, a newly hired pilot conducted a hydraulic-system-off landing, then the pilot-in-command took the controls for a normal takeoff. The helicopter rolled left, and the main rotors struck the ground. The pilot rolled the engine throttles off and righted the helicopter on its skids before the helicopter stopped. The new-hire pilot said that he saw the hydraulic light flicker, and the pilot-in-command said that a hydraulic hardover had caused the helicopter to roll. Maintenance records showed that the hydraulic-drive-belt assembly had been replaced Dec. 10, 1998.</td></tr>
<tr><td>Feb. 12, 1999</td><td>Toledo, Ohio</td><td>Aerospatiale AS 355</td><td>substantial</td><td>3 serious</td></tr>
<tr><td colspan="5">While the helicopter was being flown at night to a hospital, dispatch told the pilot that snow prevented seeing across the ramp. A company pilot suggested that he climb and execute a very-high-frequency omnidirectional radio (VOR) approach, but — without an autopilot and with only a basic instrument package — the accident pilot rejected that option. Instead, the pilot initiated a descent to land in an open area. Between 300 feet AGL and 75 feet AGL, the helicopter entered IMC. The pilot declared an emergency and continued to descend. At about 60 feet AGL, the pilot saw a 50-foot to 60-foot tree. The pilot applied aft cyclic, and the helicopter impacted the tree, continued to descend and struck a house. The helicopter came to rest upright and partially in the house.</td></tr>
<tr><td>Feb. 13, 1999</td><td>Hockley, Texas</td><td>Eurocopter BK 117B-1</td><td>substantial</td><td>5 uninjured</td></tr>
<tr><td colspan="5">Two helicopters were dispatched in day VMC to the scene of an automobile accident. During the approach, the accident pilot observed power lines parallel to the road. After the patients were loaded, the pilot of the other helicopter conducted a "safety walk-around" for the departing helicopter. He watched the helicopter lift up and drift toward the power lines, where the main-rotor blades contacted the wires. The accident pilot said that, during the takeoff, he observed "trash blowing around" and "the sun … shining directly into the windscreen." The pilot felt a slight shudder but no loss of control and set the helicopter back down in a field adjacent to the road.</td></tr>
<tr><td>April 4, 1999</td><td>Indian Springs, Nevada</td><td>MBB BO 105</td><td>destroyed</td><td>3 fatal</td></tr>
<tr><td colspan="5">Night IMC prevailed for the helicopter's repositioning flight after delivering a patient to a hospital. The weather had deteriorated, with freezing rain that turned to wet snow and freezing sleet. The helicopter was seen using its spotlight to follow the highway at about 150 feet to 200 feet. Visibility had decreased to about 50 feet when witnesses heard the sound of the impact. The aircraft was not certified for instrument flight. The pilot had completed inadvertent-IMC training within the previous 90 days.</td></tr>
<tr><td>April 11, 1999</td><td>Sarasota, Florida</td><td>MBB BK 117</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The pilot lifted the helicopter into a hover facing south in day VMC and called ATC for departure clearance. The controller asked the pilot to hold for landing traffic, then asked the pilot if he could see the landing traffic. The pilot moved the helicopter to the east looking for traffic. He then heard a thud and felt a thud, followed a second later by three more thuds. The helicopter drifted back, and the tail rotor contacted a hangar.</td></tr>
<tr><td>May 15, 1999</td><td>Rockton, Illinois</td><td>Bell 222</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The pilot flew the helicopter to a temporary landing zone in a freshly plowed field for a landing in night VMC. The pilot oriented his approach angle off the bright lights from the emergency vehicles and a ground guide with two light wands. The helicopter landed hard, damaging the nose cowl, landing skids and tail boom.</td></tr>
</table>

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>June 14, 1999</td><td>Jackson, Kentucky</td><td>Sikorsky S-76A</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">Soon after the pilot reported leaving 1,600 feet for 4,000 feet in night IMC, ATC asked the pilot to report altitude, but this transmission and subsequent transmissions were not answered. Visibility was reported as less than 0.25 mile (403 meters). Another witness heard the helicopter flying behind a hill and then heard a pop from that direction. The helicopter struck rising terrain on a tree-covered slope.</td></tr>
<tr><td>July 17, 1999</td><td>Fresno, Texas</td><td>MBB BK-117</td><td>destroyed</td><td>3 fatal</td></tr>
<tr><td colspan="5">The helicopter was being flown in day VMC to pick up a patient for transfer to a hospital when it struck terrain about 40 miles (64 kilometers) from the hospital. Witnesses said that the helicopter was being flown parallel to a highway and appeared to begin a left turn when pieces "shot out" from the top of the helicopter. The helicopter descended in a nose-low attitude behind trees and struck terrain. All four main-rotor blades separated from the main-rotor hub.</td></tr>
<tr><td>Aug. 10, 1999</td><td>Cape Girardeau, Missouri</td><td>Bell 206L</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The auxiliary-power cord was attached to the helicopter when the pilot began to take off in day VMC from a hospital helipad. The helicopter yawed left and pitched down at the edge of the fourth-floor helipad. The pilot landed the helicopter on a street, and the tail boom struck a brick wall.</td></tr>
<tr><td>Sept. 10, 1999</td><td>Kenansville, Florida</td><td>MBB BO 105</td><td>substantial</td><td>3 serious</td></tr>
<tr><td colspan="5">The helicopter was flown at night to a motor-vehicle accident on a highway. The crew encountered ground fog en route but saw lights of the emergency vehicles and descended from 1,000 feet to 700 feet to fly over the accident scene. About 300 feet above the ground, the pilot applied collective control and engine power, but the helicopter continued to descend. The helicopter struck trees and rolled onto its right side. The pilot observed no warning lights or anomalies before the accident.</td></tr>
<tr><td>Nov. 17, 1999</td><td>Neihart, Montana</td><td>Bell 206L-1</td><td>substantial</td><td>4 uninjured</td></tr>
<tr><td colspan="5">The helicopter was flown in day VMC to a ski resort to pick up a patient. After the patient was loaded and weight and balance were calculated, the pilot prepared for departure. The pilot observed periodic wind gusts of five knots to 15 knots. He said that, because of trees, he turned the nose of the helicopter 45 degrees to 50 degrees to the left, hovered to an open area and departed downslope, building speed and altitude. After the helicopter moved about 20 feet to 30 feet, the pilot felt the tail of the helicopter abruptly rotate left. The pilot applied left pedal, but that did not stop the rotation. The pilot applied cyclic control to return to the landing zone. During the maneuver, the tail rotor struck a ski-lift tower. The pilot closed the throttle and used collective to cushion the landing. The helicopter landed hard.</td></tr>
<tr><td>Jan. 2, 2000</td><td>Kalispel, Montana</td><td>Bell 206L-3</td><td>minor</td><td>2 uninjured</td></tr>
<tr><td colspan="5">In day VMC, the pilot began a takeoff from a landing zone after picking up a victim of a skiing accident. Minor damage to the tip cap resulted when the rotor blade struck a tree.</td></tr>
<tr><td>Feb. 26, 2000</td><td>Knoxville, Tennessee</td><td>Bell 412</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The pilot landed in night VMC at a roadside landing zone to pick up an injured patient. The slope of the terrain was steep, so he attempted to reposition the helicopter. He was looking out the left side of the helicopter at wires when he turned the tail to the right; the tail rotor struck a tree. The pilot reduced collective, and the helicopter came to rest on the skids. After contact, the tail rotor and tail-rotor gearbox separated from the helicopter. Flying debris from the separating components caused further damage to the fuselage.</td></tr>
<tr><td>March 10, 2000</td><td>Near Dalhart, Texas</td><td>Eurocopter BO 105</td><td>destroyed</td><td>4 fatal</td></tr>
<tr><td colspan="5">The helicopter was met by a ground ambulance crew at a landing site in a farm field, where the patient, who was suffering from respiratory distress, was transferred. The helicopter took off for the 120-mile (193-kilometer) return flight about 0600 in dark-night IMC. Witnesses observed patchy fog in the area. About 0.25 inch (6.4 millimeters) of ice had formed on vehicle mirrors and antennas. When the helicopter was late arriving, another crew was dispatched in the hospital's other helicopter to search. The crew observed wreckage in a field about 1045, as police arrived at the scene.</td></tr>
<tr><td>April 14, 2000</td><td>St. Paul, Minnesota</td><td>Bell 222</td><td>substantial</td><td>2 uninjured</td></tr>
<tr><td colspan="5">The helicopter was being flown in day VMC to a downtown airport after a patient drop-off. The pilot said that about halfway to the airport, he felt two thuds in the cyclic control in the aft direction. He turned for a downwind traffic-pattern entry. At 800 feet to 900 feet, the helicopter pitched into a severe nose-high attitude. The cyclic stick "harded over" to the full-aft position, and the pilot was unable to move any flight controls except the pedals. The helicopter climbed and dived, and the cyclic moved on its own. The pilot struggled to keep the controls centered. He realized that the helicopter would not clear the power lines, so he applied full-left pedal and placed the helicopter on the roof of a two-story building.</td></tr>
<tr><td>April 25, 2000</td><td>St. Petersburg, Florida</td><td>MBB BK 117</td><td>destroyed</td><td>3 fatal</td></tr>
<tr><td colspan="5">After transporting a patient to a medical center, the helicopter was being flown in day VMC on an eight-minute flight to the hospital operating base. The pilot flew a newly established route, developed in response to noise complaints from residents along the previous, more direct, route. A witness said that the helicopter was being flown at about 500 feet AGL when it collided with a radio transmission tower guy wire. The helicopter continued flying several hundred feet before striking a mangrove tree.</td></tr>
</table>

<table>
<tr><th>Date</th><th>Location</th><th>Helicopter Type</th><th>Helicopter Damage</th><th>Injuries</th></tr>
<tr><td>May 6, 2000</td><td>Cincinnati, Ohio</td><td>Eurocopter BK 117A-4</td><td>substantial</td><td>1 serious</td></tr>
<tr><td colspan="5">The pilot was completing his sixth flight of the night in VMC. He had refueled and was returning the helicopter to the hospital without the medical crew on board. He initiated his approach to the west side landing area from the southwest and observed the windsock indicating a light wind from the southwest. The pilot said that, after the helicopter crossed the edge of the landing area and was almost in a hover, he heard a loud noise from the rear, the left rudder pedal pushed rearward and the nose moved to the right. The pilot recognized a loss of tail-rotor thrust and closed the power levers. The helicopter struck the ground upright with both engines running. Examination of the windsock revealed that the end was caught on a crossbar attached to the windsock support structure. When the windsock was freed, it extended straight out.</td></tr>
<tr><td>July 16, 2000</td><td>Allen, Texas</td><td>MBB BK 117A-3</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">While hovering in ground effect during an approach in night VMC, the pilot attempted to move away from obstacles surrounding the landing location. When the pilot began a pedal turn to face EMS units behind the helicopter, the tail rotor struck trees. As the helicopter began to spin, the pilot lowered the collective and landed hard.</td></tr>
<tr><td>July 24, 2000</td><td>Sumner, Georgia</td><td>Eurocopter AS 350B</td><td>destroyed</td><td>3 fatal</td></tr>
<tr><td colspan="5">The helicopter was being flown in night VMC back to a hospital after transporting a patient to another hospital. About 0227, the pilot established radio contact with the dispatcher and reported a GPS location. No further transmissions were received from the pilot. When the flight failed to arrive at its final destination, a search was initiated; the helicopter was found at 0850 in a swampy, wooded area. The helicopter had struck trees.</td></tr>
<tr><td>July 28, 2000</td><td>Minneapolis, Minnesota</td><td>Bell 222U</td><td>substantial</td><td>1 uninjured</td></tr>
<tr><td colspan="5">At 1140, the helicopter lifted off from a hospital helipad in VMC for a repositioning flight, and the tail rotor struck a light. The pilot landed on the helipad and shut down the engines.</td></tr>
<tr><td>Oct. 14, 2000</td><td>Grand Canyon, Arizona</td><td>Bell 206L-1</td><td>substantial</td><td>1 minor</td></tr>
<tr><td colspan="5">The helicopter was departing in day VMC from an accident scene with a patient who had been injured in a fall. The pilot said that the helicopter rotated to the right at 80 feet AGL to 100 feet AGL and that he applied full left pedal to stop the rotation. The helicopter continued to rotate and descended into trees.</td></tr>
<tr><td>Oct. 16, 2000</td><td>Burlington, North Carolina</td><td>Aerospatiale AS 355</td><td>destroyed</td><td>1 fatal</td></tr>
<tr><td colspan="5">The main transmission had been installed after overhaul three days before the accident. About four minutes before landing at a medical center in night VMC, the main-transmission oil-pressure warning light illuminated. The pilot landed the helicopter. A maintenance technician found no excessive oil leaks and disconnected the wire from the transmission-oil-pressure switch; the warning light extinguished. The crew performed a ground run and hover check, then departed. Witnesses heard the helicopter flying at what appeared to be a low altitude. The helicopter made a steady drone and a low-velocity thumping noise. The helicopter struck trees, and a fire erupted. A post-accident inspection showed that the gears in the combiner gearbox were damaged and that the transmission-oil-pump drive shaft was separated near the midspan.</td></tr>
<tr><td>Nov. 13, 2000</td><td>Parumph, Nevada</td><td>MBB BO 105</td><td>substantial</td><td>3 uninjured</td></tr>
<tr><td colspan="5">The helicopter had been flown in night VMC to a landing site on a rural road to pick up a patient. Ground personnel had illuminated the site with headlights from an ambulance and told the helicopter crew by radio that there was no wind and that there were no wires obstructing the site. While on the downwind leg for landing, the pilot observed a car moving toward the site and told the flight nurse to inform ground personnel. When the helicopter was on short final, the pilot observed that the car had stopped in the landing site. The pilot began a go-around at a low altitude. He observed power lines in his peripheral vision and attempted to make a climbing right turn. During the turn, the right skid contacted the ground, and the helicopter rolled onto its side.</td></tr>
<tr><td>Dec. 18, 2000</td><td>West Mifflin, Pennsylvania</td><td>Aerospatiale SA 365</td><td>substantial</td><td>2 serious, 1 uninjured</td></tr>
<tr><td colspan="5">The helicopter was undergoing a 500-hour inspection after replacement of major tail-rotor components. A post-maintenance operational flight check, the fifth one, was being conducted in day VMC when a maintenance technician heard a bang, and the pilot experienced a loss of tail-rotor control. About 10 attempts were made to land. The pilot then attempted a running landing. The helicopter began a left spin with up-and-down nose oscillations and impacted the ground. The tail boom and main-rotor system broke away from the main fuselage, and the main fuselage broke in half. A post-flight inspection revealed that the fenestron and pitch-change servo-actuating-rod end were not connected to the actuating bell crank.</td></tr>
<tr><td>Dec. 22, 2000</td><td>Wilcox, Arizona</td><td>Bell 206L-3</td><td>substantial</td><td>3 minor</td></tr>
<tr><td colspan="5">The helicopter departed from a medical center after delivering a patient and was being flown to its base in night VMC. The pilot felt uncomfortable when he detected an aftertaste from something he had tried to drink about two hours earlier. About five minutes from the base hospital, nausea, sweating and cramps suddenly overcame him. He said that the night was dark and moonless and that rough terrain was below him. The airport was at his 12 o'clock position at five miles, so he decided to fly there rather than to attempt an off-airport landing. About 20 feet above the touchdown point, the pilot doubled over because of severe cramping. This moved the cyclic forward and to the right. The main-rotor blades contacted the ground, and the helicopter came to rest on its side.</td></tr>
</table>