UCSF MEDICAL CENTER AT MISSION BAY

Final Environmental Impact Report

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University of California San Francisco

September 2008

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4.3 Helicopter Aeromedical Flight Operations and Public Safety

2005 EIR

An analysis of Hazards and Hazardous Materials was presented in Section 4.3 of the *2005 EIR*. The *2005 EIR* analyzed: hazardous material associated with building demolition, hazardous materials associated with construction of the new hospital facilities, use of hazardous materials (chemicals, radioactive, biohazardous, and waste) associated with operation of the new hospital facilities, additional loads placed on hazardous waste management facilities, and hazards associated with soil and groundwater contamination.

The impacts were found to be less than significant after mitigation. Mitigation Measure 4.5-4 (page 4.5-18 of the *2005 EIR*) was adopted and would be implemented as part of the proposed project. The measure commits UCSF to:

(1) Extend its existing hazardous waste minimization plan to include any chosen site for hospital replacement,

(2) Implement operational controls and compliance audits, and

(3) Implement procedures to minimize increases in long-lived radioactive waste generation.

At the time the *2005 EIR* was written, Impact 4.5-7, page 4.5-23, committed UCSF to additional project-level analysis to assess potential safety conflicts associated with the Mission Bay hospital helipad and other existing and proposed building heights in the Mission Bay South Plan Area. The *Initial Study* prepared for this EIR focused out the topics of hazardous material generation, use and disposal and no further discussion is needed in this EIR.

The following EIR analysis identified potential new impacts and mitigation measures from the UCSF Medical Center at Mission Bay project related to aeromedical helicopter flight operations and public safety.

4.3.1 Introduction

The increased use of helicopters to bring emergency patients to a hospital may cause concern among some people who live and work near the hospital. Some may believe that there is a danger that helicopters carrying patients could crash into their homes and cause damage, injury, or even death.

This section describes various aspects of the aeromedical helicopter flight operations that would result from the introduction of a helipad to the project site, as is proposed by the UCSF Medical Center at Mission Bay project. First, this section describes the general characteristics of aeromedical helicopter flight operations and describes the associated risks. This section also considers the magnitude of the safety hazard that the proposed aeromedical helicopter flights could create for people residing or working near the proposed helipad sites.

4.3.2 Setting

Regional Setting

Aeromedical Helicopter Flight Operations

One of the most important advantages of helicopter transport is the reduction of patient transport time, often a critical component of patient survival and effective treatment. Helicopter transport also permits a medical center to serve a broad geographical region. Additionally, a helicopter's capacity to land and take-off vertically, and its ability to hover, provide access to trauma victims in areas that are normally inaccessible by foot or land vehicles. Because helicopters require less clearance space than other aircraft to land or depart, helicopters are practical to use in urban environments where space is often at a premium.

Aeromedical[1] helicopters carry specialized medical equipment and medical staff, such as paramedics and nurses, who stabilize and monitor patients and provide in-flight care. In addition to standard advanced life support equipment and supplies (EKG monitors/defibrillators, respiratory support equipment, medications), typical equipment includes oxygen, infusion pumps, ventilators, and communications equipment that allows staff to stay in constant touch with hospital staff. While the minority of transport teams include physicians, the vast majority of helicopter teams include a registered nurse. While some hospitals own and operate aeromedical helicopters, many aeromedical helicopters used by trauma centers are owned and operated privately.

Aeromedical helicopter pilots are subject to stringent certification requirements typically including minimum of 3,000 hours of flight time, 500 hours of night flight time, and other requirements for on-going training and experience under various operational conditions.[2]

Helipads can be located on the ground or atop a building. Helipads for aeromedical transport are often located atop a hospital. Typically, helipads are constructed of a strong material such as reinforced concrete[3] and are designed for the largest helicopter anticipated to use the facility. Helipad design typically includes dimensional, obstructional clearance, and load bearing criteria. In some cases the critical parameters may represent a combination of parameters from several different helicopter models. Specific standards must also be met with regard to final approach and takeoff area (FATO) and safety areas for various sizes of helicopters (these are described in more detail below).

Description of EMS Helicopter Operations

Helicopters are used in emergency medical service (EMS) work for two primary purposes: (1) delivering critically injured or ill patients to hospitals (normally termed a "scene call") and

[1] Although the term *aeromedicine* refers to diseases and disorders that result from flight in the earth's atmosphere, the term *aeromedical*, as used here, is simply an adjective that describes air transport for medical purposes.

[2] The detailed requirements of REACH and Calstar for their aeromedical pilots and flight crews are on file and available for public review at UCSF Campus Planning Office**.**

[3] A helipad constructed of asphalt might soften during hot weather, making a helicopter landing on it susceptible to tipping upon landing or departure and possible rotor contact with the helipad area, a highly undesirable situation.

(2) transferring patients (or donated organs) from one hospital to another, which is normally termed an "interfacility transfer." A scene call typically results from an incident such as an automobile accident, a hiking or mountain-climbing accident or a similar situation, in which an emergency medical personnel, upon arriving at the scene, determines that a helicopter transfer is required to transport the patient to a hospital and coordinates this effort. Because the helicopter operation proposed for the UCSF Medical Center project would be limited to interfacility transfers, only this type of aeromedical service is considered further in this EIR.

Description of an Interfacility Transfer

An interfacility transfer occurs when a patient needs to be transported from one hospital to another. Such transfers take place when the injury exceeds the capability of facilities or expertise available at the referring hospital. Transfers might be to a hospital that has more intensive services, such as a trauma center, or a particular medical specialty such as a burn ward, neonatal intensive care unit or cardiovascular operating suite. An interfacility transfer can also be used to deliver a donated organ to a recipient at another hospital. Details of the transfer are arranged by physicians at the two hospitals. For interfacility transfers, the helicopter operator dispatches an aircraft to the transferring hospital at the designated time. In most cases, each hospital has a prepared, permitted helistop with designated flight paths. Therefore, from an aeronautical perspective, these transfers tend to be of a more routine nature than a scene call. The crew receives the patient, transfers him/her to the receiving hospital and then turns the patient over to the medical personnel at that hospital. The medical crew normally monitors the patient's vital signs and maintains radio contact with the receiving hospital during the flight. The crew normally needs to fill out paperwork prior to departing from the receiving hospital. Once that is finished the helicopter returns to base.

Regulatory Setting

Federal Aviation Administration

The Federal Aviation Administration (FAA) is the agency of the U.S. Department of Transportation that is charged with (1) regulating air commerce to promote its safety and development; (2) achieving the efficient use of navigable airspace of the United States; (3) promoting, encouraging, and developing civil aviation; (4) developing and operating a common system of air traffic control and air navigation for both civilian and military aircraft; and (5) promoting the development of a national system of airports.

The Federal Aviation Administration's Heliport Design Advisory Circular (AC 150/53990-2A) defines the final approach and takeoff area (FATO), and safety areas for helipads. These areas must be maintained clear of obstructions extending above landing pad elevations.

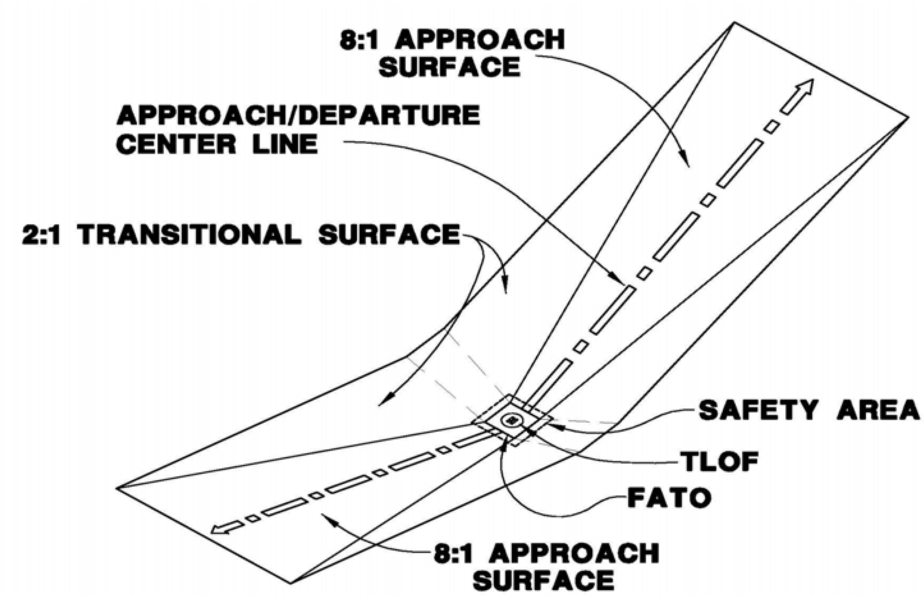
California Department of Transportation (Caltrans)

Caltrans' Division of Aeronautics issues permits for all helipads in the State of California. Helipads must meet the FAA's FATO standards in order to obtain a Caltrans operating permit. In addition, as a pre-requisite to receiving Caltrans approval of a Heliport Site Approval Permit, UCSF would be required to obtain approval from the San Francisco Board of Supervisors for the construction and operation of a helipad within City limits.

Design and Operational Considerations

Throughout the review and approval process, various design and operational elements will be considered by FAA, Caltrans, and the City of San Francisco in deciding whether to approve the proposed helipad. These requirements are intended to provide a safe operating environment for helicopters close to the helipad and include the following components:

- **dimensional requirements** to allow room to maneuver gurneys around a helicopter;
- **obstruction-related clearance requirements**, which are a series of "imaginary surfaces" in the airspace surrounding a helipad, and include the following (see Figure 4.3-1):
  - Final approach and takeoff (FATO) area, which is a horizontal plane at landing pad elevation with dimensions of 1.5 times the design aircraft's overall length (includes full forward and aft extension of main and tail rotors). FATO area is intended solely to ensure obstruction-free airspace and does not necessarily represent a solid surface. Therefore, it can extend beyond the physical helipad into the surrounding airspace.



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SOURCE: Heliplanners

Figure 4.3-1
Heliport Imaginary Surfaces Exhibit
Isometric View (not to scale)

  - Approach surfaces, which are areas that extend up and out from the primary surface edges along the designated flight paths. They are trapezoidal in shape, with a 8:1 slope (eight feet horizontal to one foot vertical) and a length of 4,000 feet. They are oriented with local prevailing winds as well as to avoid obstructions and are designed to avoid noise-sensitive areas, as feasible.

- Transitional surfaces are areas that extend up and out to the sides of the primary and approach surface edges, with 2:1 slopes (two feet horizontal to one foot vertical) and a width of 250 feet with either side of the flight path centerline.

- Safety areas are areas that surrounds the FATO area at FATO elevation and must be maintained clear of obstructions above FATO elevation.

- **load bearing capability** at a minimum of 14,000 pounds dead load and 21,000 pounds impact load, but could be constructed to accommodate larger aircraft.

4.3.3 Significance Criteria and Analysis Methodology

Significance Criteria

The introduction of helicopter aeromedical flight operations as a result of the proposed project would contribute to increased risks associated safety hazards for people residing or working near the proposed helipad. At the time of writing, there are no State or Federal regulations that set aeromedical transport standards for helipad operations. There are no criteria for determining the impact of conducting aeromedical transports for a hospital project. For the proposed project, statistical research was conducted in evaluating whether project operation of a helipad could increase the likelihood of an accident to occur in the project vicinity. See Impact Methodology, below.

Impact Methodology

It is assumed that those who live and work near the project site (the “third parties”) would be involuntarily subject to the airborne risks of death, injury, or property damage, as a result of the proposed nearby aeromedical helicopter operation. This analysis, therefore, focuses on risks to third parties on the ground, rather than on patients, pilots, or other emergency-services personnel, who voluntarily choose to, in the case of patients, be transported via a helicopter, or in the case of helicopter flight crew, work in the profession that involves some inherent risk.

To assess potential impacts from the proposed helicopter operations to affected third parties, statistics with respect to the rates and types of accidents that currently exist nationwide for helicopter operations, with particular emphasis on aeromedical helicopters, were reviewed and evaluated. Data collected by the US National Transportation Safety Board, in addition to other available information, was examined to determine whether any conditions increase the chances of an accident to occur and what types of injuries (fatal and otherwise) have occurred as a result of these accidents. Next, the proposed helipad at the project site was analyzed to determine whether any circumstances exist that would increase the likelihood of an accident to occur in the project vicinity. Expert evaluation was used to interpret the data and reach supportable conclusions.

The review and evaluation were performed by Arnold Barnett, the George Eastman Professor of Management Science at Massachusetts Institute of Technology. Professor Barnett’s review, which examined public safety risks specific to the proposed project helipad, is presented in his report, "Risk Assessment for Helicopter Operations at the University of California-San Francisco Medical Center at Mission Bay", included in the Appendix of this EIR. The impacts and discussions that follow in *Sections 4.3.4* and *4.3.5* are based on that report and refer back to the citations and references used and listed therein.

4.3.4 Impacts and Mitigation Measures

Impact MCMB.3-1: The proposed project would result in a negligible risk to human safety from aeromedical helicopter operations in the vicinity of the proposed helipad site. (Less than Significant)

As described in Chapter 3, *Project Description*, the aeromedical helipad proposed as part of the project would be situated at 140 feet (approximately 40 feet taller than the roof height of other Medical Center towers) at the northwestern corner of the Outpatient Building. For purposes of the environmental analysis, it is assumed that an average of 1.4 transports would occur on a typical day, and 3 transports would occur on a busy day.

Once the project is implemented, UCSF would contract primarily with REACH, Calstar, or both companies to provide interfacility transfer services. REACH and Calstar both employ helicopters with turbine engines, and turbine-powered helicopters would be used to serve the proposed project. According to National Transportation Safety Board (NTSB), data collected over the period of 1997 through 2006 indicates that turbine-powered helicopters averaged 1.1 fatal accidents per 100,000 flight hours, or approximately one fatal accident per 90,000 hours of flight. Assuming that an average helicopter flight is approximately 20 minutes long, the accident rate for a turbine helicopter is one fatal accident per 270,000 flights.

The accident rate for medical helicopters in slightly higher when compared with this number and averages approximately 1.8 fatal accidents per 100,000 flights. Using the 20 minute estimate for an average helicopter flight, as assumed above, this equals to approximately one fatal accident per 180,000 flights.

This risk is increased where the landing site is unfamiliar to the pilot, which is more common during scene calls and would not be the case for the proposed project. Of the 56 fatal accidents in US that involved medical helicopters (1991-2007), four occurred while landing or taking off from a hospital helipad. This rate equals to approximately 1 in 2.5 million and is considered a measurable yet very small risk. None of the four fatal helicopter events at the hospital caused any ground deaths to third parties, although in one accident, a hospital security guard who was helping service the helicopter was fatally injured. Moreover, based on the statistics associated with medical helicopter operations since 1991 in the United States, the observed risk to third parties has been zero.

The helicopter flight operations risk associated with the proposed project would likely be lowered further by the fact that the proposed helipad would be sited in close proximity to the bay where no physical barriers exist to obstruct views of the approach. Furthermore, REACH and Calstar have performed over 69,000 hours of service in combination, and have suffered one fatal accident, a rate that is consistent with the overall accident rate statistics described above. The accident that occurred did not cause any fatalities on the ground.

Statistics also reveal that helicopter accidents that cause serious injuries to third parties or substantial property damage are also extremely rare. Out of 132 incidents involving medical helicopters from 1991 to 2005,[4] none caused serious injury to a third party and one caused modest damage to a hospital building.[5]

Based on information documenting national helicopter safety patterns provided above, it can be assumed that, while the risk of death or injury to third parties, and risk of property damage to structures near the project site is not zero, this risk is very small. The twelve million medical helicopter flights in the US since 1991 have caused no deaths to third parties in the vicinity of hospitals. Based on this and other statistics noted above, the likelihood of a third party death resulting from the operation of the proposed interfacility transfer operation is also extremely small.

Mitigation: None required.

4.3.5 Cumulative Impacts

Impact MCMB.3-2: The potential construction of another helipad at the San Francisco General Hospital site (approximately 1.5 miles from the UCSF site) may result in an increased risk related to operation of two helipads in the same general area. (Less than Significant)

Presently, many aircraft, including news helicopters, fly through the project area on typical day. In the event that an additional helipad is developed at the San Francisco General Hospital site, there may be a perceived increase in risk associated with the combined flight operations at the two facilities. However, based on the overall statistics observed in NTSB data, this risk would be insubstantial and would not add, in any meaningful way, to the third-party risk level that is already extremely small. Furthermore, FAA flight rules ensure safety by requiring pilots to communicate with each other regarding their locations and planned flight track.

Based on data available since 1991, the roughly 100 million helicopter flights in the United States have generated seven fatal collisions involving two helicopters. This rate—one collision involving two helicopters per 14 million flights—implies that collisions contribute only about 5% of the fatal accident risk for a given helicopter flight. Furthermore, none of those seven collisions caused any deaths to third parties.

4 This statistical record was achieved in the course of approximately twelve million medical helicopter flights.
5 One medical flight hit a home after losing visibility en route, causing serious injury to three occupants. But this accident was not close to the hospital.

Therefore, the operations of a second helipad within a relatively close distance to UCSF would not be expected to raise risks associated with the operating a helipad at the project site.

Mitigation: None required.

References – Helicopter Aeromedical Flight Operations and Public Safety

Barnett, Arnold, *Risk Assessment for Helicopter Operations at the University of California-San Francisco Medical Center at Mission Bay*, March, 2008.

APPENDIX

Risk Assessment for Helicopter Operations at the University of California San Francisco (UCSF) Medical Center at Mission Bay

Arnold Barnett

Risk Assessment for Helicopter Operations at the University of California San Francisco (UCSF) Medical Center at Mission Bay

Arnold Barnett
George Eastman Professor of Management Science
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March 2008

Helicopter operations have never taken place at University of California, San Francisco (UCSF) Medical Center at Mission Bay, so there is understandable concern about whether they might pose appreciable risks to the hospital and surrounding community. Here we review various forms of empirical evidence to assess how great such risks might be. To state the conclusion succinctly, the risks are so close to zero as to be virtually unmeasurable.

Our focus is on the risks that helicopter operations present to *third parties on the ground* who are not directly involved with the air ambulance service, rather than to those in the helicopter itself such as patients, pilots, or such emergency services personnel as on-board nurses. For patients, any risks of helicopter travel are presumably dwarfed by the dangers of not reaching the hospital as quickly as possible. For pilots and on-board medical attendants, the risks can be construed as occupational hazards of their chosen work. But for those who live and work near helicopter landing sites ("third parties"), the airborne risks of death, injury, or property damage are not voluntary, and they deserve explicit consideration.

Fatal Accident Risk to Third Parties

Clearly, the most frightening prospect for third-party citizens is of being killed in a helicopter accident near the hospital helipad. But the fact that we can visualize such an event does not mean that it reflects a genuine risk. The helicopters that would serve UCSF Medical Center would have turbine engines: over the decade 1997-2006, National Transportation Safety Board

(NTSB) data show that turbine-powered helicopters averaged 1.1 fatal accidents per 100,000 flight hours. That works out to one fatal accident per 90,000 hours of flight. NTSB estimates that the average helicopter flight is about 20 minutes long, meaning that turbine helicopters experienced approximately one fatal accident per 270,000 flights (90,000*3). The statistics for medical helicopters alone have been higher, at an estimated 1.8 fatal accidents per 100,000 flight hours. That works out to approximately one fatal accident per 60,000 hours of flight, or—using the 20-minute estimate again--to *one fatal accident per 180,000 flights*.

There is a further point of great importance: the fatal accidents of medical helicopters rarely take place in the immediate vicinity of a hospital helipad. Far more likely, the accident will occur either en route or at a distant landing site unfamiliar to the pilot (e.g. the location of an automobile accident). Of the 56 fatal events in the US that involved medical helicopters over 1991-2007, only four occurred while landing or taking off at the hospital. Thus, fatal crashes near the hospital occurred at a rate of approximately (4/56)*(1 in 180,000) *= 1 in 2.5 million*.

Moreover, there is the issue of who suffered the fatal injuries. None of the four fatal helicopter events at the hospital caused any ground deaths to third parties[1]. The same holds true for all 18 fatal accidents for medical helicopters that took place over 1991-2007 on either takeoff or landing. In other words, the observed risk to third parties was *zero* for all the millions of medical helicopter operations since 1991 in the United States. That circumstance, however, does not prove that future risk will literally be zero. To be conservative in making a risk projection, we might move towards a worst-case scenario and assume that the chance that a fatal landing or takeoff accident will cause third-party deaths is as high as 10%. (If that were true, then that the

[1] In one accident, a hospital security guard who was helping service the helicopter was fatally injured.

recent record--0 out of 18--involved a healthy dose of good luck[2]). Even then, third-party victims would arise near the hospital at a rate of (1/10)*(1 in 2.5 million), which is once in every 25 million helicopter flights.

Against this backdrop, we should note that helicopter operations at UCSF are estimated to entail 1000 flights per year: 500 arrivals and 500 departures. If each flight brought a 1 in 25 million chance of causing third-party deaths at the hospital, the operations would be expected to go on for 25 million ÷ 1000 = *2,500 years* before the first such deaths occurred there.

Do any special aspects of the UCSF operations lessen the relevance of these projections, which are based on the recent experience of all US medical helicopters? It does not appear so. The designated approach path for the helicopters is over San Francisco Bay, so there are none of the physical obstacles that have caused some past accidents. The two main companies that would provide the helicopter service—REACH and CALSTAR—have performed 69,000 hours of service between them and suffered one fatal accident, which is better than the national EMS fatal-accident rate (cited above). That one accident caused no fatalities on the ground. Both companies have avoided even a single death among the 60,000 patients they transported. There is no reason to believe that the landing site itself—which would need approval by Caltrans—would pose special difficulties. And, given that historical mortality risk to third-parties is close to nonexistent at all times of day, the UCSF's specific operations schedule is immaterial to a risk projection.

It is possible that another medical helicopter service will be initiated in the Bay Area at San Francisco General Hospital, which would land approximately 1.5 miles from the UCSF site. But

[2] If third-party risk were really 1 in 10 for each of the 18 takeoff/landing accidents, the probability of avoiding third-party deaths in all 18 would be below 1 in 6.

such operations would not be expected to raise risks associated with the UCSF service. The most obvious fear is that two helicopters traveling to the different sites would collide. NTSB data show that, since 1991, the roughly 100 million helicopter flights in the United States have generated seven fatal collisions involving two helicopters. This rate—one collision involving two helicopters per 14 million flights—implies that collisions contribute only about 5% of the fatal accident risk for a given helicopter flight. This despite a huge number of situations in which different helicopters either shared landing sites or used adjacent ones. None of the seven collisions caused any deaths to third parties. Such a record suggests that the risk of a collision near UCSF only augments to a minuscule extent a third-party risk level that is already minuscule.

Serious Injuries and Major Property Damage

While less alarming than deaths, helicopter accidents that cause either serious injuries to third-parties or considerable damage to homes or offices are of obvious concern. But the data suggest that such outcomes are exceedingly rare in the vicinity of hospitals. On NTSB's listing of 132 accidents/incidents involving medical helicopters over 1991-2005, *not one* caused serious injury to a third party near a hospital, while one caused modest damage to a hospital building[3]. This record was achieved in the course of some eight million medical helicopter flights. (A review of NTSB records for 2006-07 also reveals no medical helicopter accidents that injured third parties or damaged their homes.)

Final Remarks

The eight million medical helicopter flights in the US since 1991 have caused no deaths to third parties in the vicinity of hospitals. (In a previous report based on NTSB data going back to 1983—the first full year of electronic NTSB records---the author found that the same is true for

[3] One medical flight hit a home after losing visibility en route, causing serious injury to three occupants. But this accident was not close to the hospital.

1983-90.) The flights have likewise caused no serious third-party injuries or major damage to homes near hospitals. While third-party risk is clearly not zero, efforts to quantify the hazards using broader data about turbine-powered helicopters yield miniscule risk projections for the UCSF Medical Center, which plans only about 1000 helicopter operations per year. UCSF's helicopters will arrive and depart over San Francisco Bay; thus, if risk levels at UCSF do deviate from national patterns, it appears more likely that they would be lower rather than higher.

Reference:

1. U.S. National Transportation Safety Board, U.S. Civil Helicopter Safety Statistics-Summary Report 1997-2006

2. Baker S. P., J.G. Grabowski, R.S. Dodd, D. F. Shanahan, M.W. Lamb, and G. H. Li, (2006), "EMS Helicopter Crashes: What Influences Fatal Outcome?," *Annals of Emergency Medicine* vol 47 (4), April 2006, pp. 351-356

3. US National Transportation Safety Board, Aviation Accident Database & Synopses, available at *http://www.ntsb.gov/ntsb/query.asp*. Used aircraft category "helicopters" and reviewed details of all medical helicopter accidents over the period 1991-2007. Also reviewed midair collisions of helicopters.

4. *Helipad Information Sheet*, UCSF Medical Center, Mission Bay Hospital Site, Revised October 24, 2007.

5. Written communication from Brian Watts of Heliplanners (brianwatts@heliplanners.com)

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Arnold Barnett is George Eastman Professor of Management Science at MIT's Sloan School of Management. He holds a BA in Physics from Columbia University and a PhD in Mathematics from MIT. Dr. Barnett's research speciality is applied statistical analysis generally focused on problems of health and safety. His early work on homicide risk was presented to President Ford at the White House, and his studies of US Vietnam war casualties were the subject of a column by William F. Buckley Jr. Aviation safety is among his prime areas of application: he has been described as "the nation's leading expert" on aviation safety by NBC News, and he received the President's Citation in 2002 from the Flight Safety Foundation for "truly outstanding contributions on behalf of safety." He has received the President's Award for "outstanding contributions to the betterment of society" by the Institute for Operations Research and the Management Sciences (INFORMS); he also received the 2001 Expository Writing Award from INFORMS and is a Fellow of that organization. Ten times the students of MIT's Sloan School have honored him for outstanding teaching.

<u>Primary Research Interests</u>: Operations Research, Applied Statistics, Applied Mathematical Modeling, Public Policy, Health and Safety

<u>Outside Experience:</u>

1973-75	U. S. Atomic Energy Commission (Bethesda, MD)
1975	Norton Publishing Co. (New York)
1975-90	Public Systems Evaluation Inc., Enforth (Cambridge)
1975	U. S. Dept. of Justice, Law Enforcement Assistance Administration (Washington)
1976-81	Tufts-New England Medical Center, Dept. of Hematology (Boston)
1978-81	U. S. General Accounting Office, Division of Energy and Minerals (Washington)
1980	Vermont State College System
1980	Citizens Crime Commission of New York City
1981	Professional Development Institute, Ltd. (Ottawa)
1982-84	National Center for State Courts (Williamsburg, Virginia)
1984	Manchester Business School (sabbatical)
1984-present	Educational Testing Service (Princeton, New Jersey)
1984-85	McKinsey and Company (London, Sydney)
1985	Australian Graduate School of Management (sabbatical)
1987	U. S. Sentencing Commission (Washington)
1987-95	KOBA Associates (Washington)
1988	Abt Associates (Cambridge)
1988	MacArthur Foundation/National Institute of Justice

1989	Centers for Disease Control (Atlanta)
1990-91	U.S. General Accounting Office (Washington)
1990-91	Federal Aviation Administration (Atlantic City)
1992-94	Burns and Levinson, Counsellors-at-Law, Boston
1992-3	Clinton and Musaka, Counsellors-at-Law, Boston
1993-present	Amsterdam Schiphol airport
1993	American Airlines
1993-present	Analysis Group (Cambridge)
1994	Goodwin Proctor and Hoar, Counsellors-at-Law, Boston
1994-95	Newsweek magazine
1994	CSSI (Washington)
1994	Liberty Mutual Insurance
1995-99	Computerworld magazine
1995	ATMS (Falls Church, VA)
1995	Ropes and Gray, Counsellors-at-Law, Boston
1995	Association of American Railroads
1996	Verner, Liipfert, Bernhard, McPherson, and Hand (Washington)
1996	Morgan-Stanley, Hong Kong
1996-present	Gell-Mann Research Associates (Philadelphia)
1997-present	Environmental Science Associates (San Francisco)
1997	Volpe National Transportation Center
1997	Coopers & Lybrand
1997	Holland & Knight Law Offices (Miami)
1998-present	Federal Express Airlines
1999	Connecticut Home Care Association
1999	Locke, Liddell, and Sapp (Counselors at Law) (Houston)
1999-present	Urban Institute (Washington)
1999-present	J.P. Morgan and Co.
1999-present	McNatt, Greene, and Thompson Law Offices (Vidalia, GA)
2000	Amsterdam Schiphol Airport, Committee on Crosswinds and Tailwinds
2000	University Access Inc. (Los Angeles)
2000	American Association of Actuaries
2000	O'Melveny and Myers (Los Angeles)
2000	Louisville International Airport
2001-present	Cornerstone Research, (New York, Los Angeles, Menlo Park)
2001	Flight Safety Foundation
2001	Jenner and Block, (Chicago)
2001	Simpson, Thacher, and Bartlett (New York)
2000-present	Sonnenschein, Nath and Rosenthal, (Kansas City, Chicago, St. Louis)
2002	(US) Transportation Security Administration
2002	Wollmuth, Maher, and Deutsch (New York)
2002	Finnegan, Henderson, Farabow, Garrett, and Dunner (Washington)
2003	MCRI (Arlington, Virginia)
2004	Johnson and Johnson, Inc (New Jersey)
2004	Wilson, Sonsini, Goodrich, and Rosati (Palo Alto)
2004-present	Winston and Strawn (Chicago)
2005	Manatt, Phelps, and Phillips (New York)
2006-07	De Brauw Blackstone Westbroek (The Hague)

2007 Morrison and Forester (Sacramento)

Teaching Honors:

Selected ten times by the students as recipient of an MIT Sloan school or institute-wide Excellence in Teaching Award. One of eight U. S. faculty discussed in the article "B-School Students' Favorite Professors" in Fortune magazine of January 25, 1982. Ranked the most "outstanding" faculty member at the Sloan School in a 1992 Business Week poll of recent graduates. (The Best B-Schools, McGraw Hill, 1993, p. 165)

Research Honors

Awards and Honors: 1996 President's Award from Institute for Operations Research and the Management Sciences (INFORMS) for outstanding contributions to the betterment of society.

Selected as the 1999 honorary inductee into Omega Rho International Honor Society for scholarly contributions

Selected by the British Operational Research Society as the year 2000 Blackett Memorial Lecturer; lecture was delivered at the Royal Aeronautical Society

Recipient of the 2001 Expository Writing Award of the Institute for Operations Research and the Management Sciences (INFORMS) because influence of research was "greatly enhanced by its expository excellence."

Recipient of 2002 President's Citation from the world-wide Flight Safety Foundation for "truly outstanding service on behalf of safety, whether it be valor, professionalism or other service above and beyond expectations."

Selected in 2003 as a Fellow of the Institute of Management Sciences and Operations Research

Aviation-Related Publications:

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"Speed Kills?" pp. 63-68, March-April. Volume 16
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"Take the Bargain and Fly," *Advancing the Consumer Interest*, April 1990. (The negative side in a debate on whether the pernicious aspects of U.S. airline deregulation outweight the economic benefits it has brought to travelers.)

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