Aviation Safety Support Services for the Bureau of Safety and Environmental Enforcement

Task C.4.5: Study on Effects of Combustible Gas on Helicopter Operations

August 31, 2015

Table of Contents

Table of Figures

Table of Tables

Abbreviations and Acronyms

APG – Associated petroleum gases (methane, ethane, propane, and butane).

API – American Petroleum Institute

ANAC - National Civil Aviation Agency (of Brazil)

BACT - Best Available Control Technology

BSEE - Bureau of Safety and Environmental Enforcement

CAA – UK Civil Aviation Authority

CASA - Civil Aviation Safety Authority (of Australia)

CFD – Computational Fluid Dynamics

CONUS – Continental United States

EASA - European Aviation Safety Agency

EPA – Environmental Protection Agency

EEZ - Exclusive Economic Zone

FAA – Federal Aviation Administration

FADEC - Full Authority Digital Engine Control

FATO - Final Approach and Takeoff Area

FPSO - Floating Production and Storage Offloading equipment

HAI - Helicopter Association International

HMS - Helicopter Monitoring System

HSAC – Helicopter Safety Advisory Conference

ICAO - International Civil Aviation Organization

IFR - Instrument Flight Rules

INAC - Instituto Nacional de Aviação Civil (of Angola)

ISO - International Standards Organization

IUPAC - International Union for Pure and Applied Chemistry

Jet A – aviation turbine fuel specification for Jet A and Jet A-1 in accordance with ASTM D1655.

LFL - Lower Flammable Limit

MGTOW - Maximum Gross Takeoff Weight

MIE - Minimum Ignition Energy

MODU – Mobile Offshore Drilling Unit

NAAQS - National Ambient Air Quality Standards

NIST - National Institute for Standards and Technology

NORSOK – (Norsk Sokkels Konkuranseposisjon) standards developed by the Norwegian Technology Centre

NTSB - National Transportation Safety Board

OCS – Outer Continental Shelf

OSHA - Occupational Safety and Health Administration

PMx - Particulate Matter

PORV - Pressure Operated Relieve Valves

PSD - Prevention of Significant Deterioration

USCG - United States Coast Guard

VCE - Vapor Cloud Explosion

VFR - Visual Flight Rules

VOC - Volatile Organic Compounds

1. *Introduction*

As a result of two offshore helicopter mishaps involving support of the Outer Continental Shelf (OCS) oil & gas industry (and possibly others), the National Transportation Safety Board (NTSB) issued five safety recommendations to the U.S. Department of the Interior, the United States Coast Guard, and the American Petroleum Institute, to address occurrences of total or partial loss of engine power on turbine-powered helicopters due to inadvertent ingestion of methane gas[1]

As a result of the NTSB safety recommendations, the Bureau of Safety and Environmental Enforcement (BSEE) issued Solicitation, Contract and Award No. E14PS00012, Aviation Safety Support for the Bureau of Safety and Environmental Enforcement. C.4.5 Task 5 of this contract requires the assessment of potential effects to helicopter operations of methane and other combustible gasses on or near OCS helidecks to identify and mitigate or eliminate risks.

In 2011, Baker, Shanahan, and Haaland, et al, researched helicopter crashes related to offshore oil and gas operations in the Gulf of Mexico (GOM). The authors found that during the 26 year period from 1983 to 2009, 178 helicopters crashed in the GOM, nearly seven per year. 54 crashes (30%) involved 139 fatal injuries. The predominant failure in the mishaps was partial or total loss of engine power which occurred in 31% of fatal crashes and 71% of nonfatal crashes. The causes of the engine failures were varied, including engine component failures, foreign object debris ingestion, fuel contamination, and fuel starvation.

Bell 206L-3, N32041 at Main Pass 61A, March 24, 2011 (NTSB CEN11LA252)[2]

On 24 March 2011, about 1655 central daylight time, a Bell 206-L3 helicopter experienced a partial loss of power to its Allison 250-C30 turboshaft engine shortly after takeoff from an offshore oil production platform in the Gulf of Mexico. The commercial pilot initiated an autorotation and activated the helicopter’s float system; the helicopter impacted the water and rolled inverted. The pilot and two passengers received minor injuries, and the helicopter was substantially damaged. The pilot and passengers reported hearing a loud bang just after the helicopter departed the platform, toward the northwest, into the wind. After hearing the bang, the pilot observed a high indication on the torque gauge and initiated an autorotation, stating that the aircraft was above and just beyond an “exhaust pipe” on the platform but that he did not know what it vented or whether it was venting when the takeoff was initiated.

The platform operator reported that the flare boom was venting methane throughout the day, including the time of the helicopter’s departure. The offshore facility was not equipped to provide any visual indication when hydrocarbon gases were venting. Review of the data from the helicopter’s full authority digital engine control (FADEC) system revealed a slight increase in engine torque and turbine outlet temperature. The National Transportation Safety Board (NTSB) determined the probable cause of this mishap as “the loss of engine power due to an engine

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[1] Appendix C-NTSB Safety Recommendations A-14-67 through -71

[2] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

compressor stall as a result of ingesting methane gas during takeoff." See NTSB Factual Aviation Report CEN11LA252 attached as Appendix A.

Bell 407, N53LP at Ship Shoal 208H, August 13, 2013 (NTSB CEN13FA491)[3]

On August 13, 2013, a Bell 407 helicopter experienced a total loss of power to its Rolls-Royce 250-C47B turboshaft engine shortly after takeoff from an offshore oil platform in the Gulf of Mexico. The pilot reported hearing a loud bang and attempted to increase the helicopter's forward airspeed but was unable. He, then, took mitigating actions once impact with the water was imminent. The pilot and two passengers sustained minor injuries, and the helicopter was substantially damaged. The NTSB's investigation of this mishap is still ongoing. Preliminary analysis of data from the helicopter's FADEC system indicated an engine surge condition just after takeoff. After about one second of the abnormally high engine operating condition, engine power dropped and an engine flameout occurred. Power to the rotor system was regained about four seconds later, but the helicopter's altitude was too low for the pilot to be able to recover.

The pilot reported that before departure, he brought the helicopter into a stationary hover in the middle of the helideck and made a "left pedal turn into the wind and in a direction to avoid the flare boom." According to a monthly gas flaring and venting volume summary provided by the platform operator, the volume of methane vented on the day of the accident was the highest of the month and about 20 times the volume of the second highest day. See NTSB Factual Aviation Report CEN13FA491 attached as Appendix B.

1.1 *Other Mishaps Consistent With APG Ingestion*

Additionally, a detailed review of NTSB data sources uncovered numerous other helicopter incidents and accidents involving flight support of the OCS oil & gas industry that could also have involved loss of power due to ingestion of associated petroleum gases (APG). This review revealed 10 additional mishaps which are consistent with a loss of engine power due to the ingestion of APGs, including methane, from cold flaring on offshore facilities. APG ingestion was identified, by the NTSB, as the direct and proximate cause of one mishap.

Bell 206B-3, N2750F at unidentified platform near Grand Isle, LA, February 26, 1992 (NTSB FTW92LA075)[4]

During an approach by a Bell 206B-3 to a helideck, the pilot experienced a partial power loss and subsequently made a successful autorotation. Due to the high sea state, the pilot elected to maintain idle power to avoid tail boom contact with the main rotor blade while awaiting rescue.

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[3] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

[4] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

Bell 206L-3, N347AL at Marathon SP86, May 2, 1995 (NSTB FTW95FA186)[5]

During the final approach to an offshore oil platform, a Bell 206L-3 flew into the plume of an ignited flare boom. When the pilot attempted to add power to arrest the descent and bring the helicopter to a hover for landing, the engine did not respond. The helicopter settled and collided with the edge of the helideck, descending inverted into the water. The pilot and passenger egressed the airframe unaided and were rescued by a boat in the vicinity. The rear passenger failed to egress the airframe and drowned. The pilot stated that a low rotor warning sounded just prior to the helicopter striking the helideck but no engine warning was annunciated.

The helicopter was recovered and an examination of the airframe, drive train, systems, and engine was conducted. The examination provided no evidence of pre-impact failure or malfunction; the fuel pump, fuel control, governor, bleed valve, and fuel nozzle were tested and operated within design parameters.

Bell 206L-3, N81SP at West Cameron 149, March 6, 2004 (NTSB FTW04LA088)[6]

Approximately 10 seconds after takeoff from an offshore platform, the pilot of a Bell 206L-3 heard a loud bang and the engine lost partial power. The pilot initiated an autorotation to the water, and then heard a subsequent bang. Prior to touchdown, the pilot attempted to inflate the floats; however, the floats did not inflate. The pilot executed a flare, "pulled in pitch"; the helicopter "still had power" and entered into a hover. The pilot reported the helicopter "seemed to still be pulling in power when the [helicopter] touched the water then rolled and the blades hit [the water]." One occupant received minor injuries. Inspection of the engine revealed minor damage to the compressor diffuser vane and the impeller, and foreign object damage (FOD) in the combustion chamber. It was not determined if the FOD occurred prior to the impact with the water. The reason for the partial loss of engine power was not determined.

Bell 206B, N496RL at South Timbelier 187, November 5, 2004 (NTSB DFW05LA017)[7]

A Bell 206B sustained substantial damage during a forced autorotation landing into open ocean water near an offshore platform in the Gulf of Mexico. The commercial pilot sustained serious injuries; one of his two passenger's sustained minor injuries; and one passenger was not injured.

The operator reported that the helicopter departed from the platform and climbed to an altitude of 500 feet above ground level (AGL). As the pilot switched radio frequencies to make a courtesy call to the destination platform, he heard a "loud bang," and then the engine lost power. The pilot initiated an autorotation and deployed the emergency skid-mounted float system. Approximately 50-60 feet above the rough ocean water, the pilot "started to flare and selected a wave to land on." The helicopter landed hard on the water, and remained upright for approximately 20

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[5] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

[6] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

[7] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

minutes before it rolled over inverted and partially submerged. The helicopter remained floating inverted near the surface.

The pilot and two passengers evacuated the helicopter immediately after touchdown without deploying the emergency on-board life raft. Approximately 30 minutes after the accident, another helicopter arrived and dropped an emergency life raft into the water for the pilot and crew until further assistance could arrive.

Recovery efforts were initiated and, during the recovery process, the skids of the helicopter separated from the fuselage and the helicopter sank. Ocean depths were approximately 180 feet in the area of the accident and recovery efforts ceased. The helicopter was not recovered. The reason for the loss of engine power was undetermined.

Bell 206B, N3RL at East Cameron 219, May 11, 2007 (NTSB DFW07LA109)[8]

A pilot of a Bell 206B lost control of the helicopter while attempting to takeoff from an offshore platform. The pilot lifted the helicopter into a three to five foot hover and performed a final check of the "gauges." Reportedly, the torque was indicating 96 percent and all other gauges were within "normal" parameters. The pilot then attempted to transition to forward flight. The pilot reported that the helicopter "appeared to settle as it approached the deck edge and did not feel like it was in transitional lift." After the helicopter crossed the edge of the deck, it entered into an un-commanded descent and right rotation. The pilot deployed the helicopter's floats prior to impacting the water. The pilot and passengers were able to egress the helicopter into a life raft unassisted. The temperature at the time of the mishap was 80 degrees Fahrenheit. At the time of the mishap, the helicopter was calculated to be 116 pounds below allowable maximum gross weight. A post-accident examination of the helicopter revealed no pre-impact mechanical malfunctions or failures.

Although the NTSB determined that the probable cause(s) of this accident were the pilot's failure to establish a climb and maintain directional control of the helicopter while departing the offshore platform, the mishap is consistent with a momentary un-commanded power roll-back of the engine.

Bell 206L-3, N330P at High Island 138, July 22, 2007 (NTSB DFW07LA169)[9]

The pilot of a Bell 206L-3 lost control of the helicopter while attempting to takeoff from an offshore platform. The pilot performed a pre-departure check of the engine instruments. He then increased collective to gain altitude, as he lowered the nose of the helicopter to gain forward airspeed, and continued his takeoff run. During the takeoff run, as the helicopter neared the edge of the 28 by 28-foot helipad on the platform, the nose of the helicopter yawed to the left, and the helicopter began to descend. The helicopter's right skid collided with a solar panel mounted to the heliport's railing, and the helicopter continued over the edge of the platform descending

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[8] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

[9] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

vertically into the water, about 70-feet below. The pilot reported that he felt that he had experienced a partial loss of engine power which resulted in his loss of control. The pilot further stated that he did not have time to deploy the skid-mounted emergency floats before the helicopter entered the water, and subsequently sank. The temperature at the time of the mishap was 97 degrees Fahrenheit. At the time of the mishap, the helicopter was calculated to be 50-pounds below its maximum gross weight. A post-accident examination of the helicopter and the powertrain did not reveal any pre-accident mechanical anomalies or discrepancies. The three occupants did not receive any injuries.

Although the NTSB determined that the probable cause(s) of this accident were the pilot's failure to maintain rotor RPM during takeoff, the mishap is consistent with a momentary un-commanded power roll-back of the engine.

Bell 206L-4, N317RL at South Timbalier 178A, July 26, 2010 (NTSB CEN10IA438)[10]

During takeoff from an offshore oil platform, the pilot of a Bell 206L-4 reported a loss of main rotor rpm. The pilot activated the emergency float system and initiated an autorotation to the water. Upon touchdown, the engine was still operating. The pilot shut down the engine and prepared the passengers to evacuate. All three occupants safely evacuated the helicopter (which was upright on its skid-mounted float system) and boarded the emergency life raft that the pilot had inflated. The helicopter remained upright floating on the water and was later recovered and transported to the operator’s on-shore maintenance facility. The operator did immediate fuel quality tests at the facility where the helicopter had most recently been refueled and found no problems.

An examination of the helicopter drive systems and a test run of the engine did not reveal any pre-incident anomalies that would have precluded normal operation of the main rotor system. The cause of the loss of main rotor rpm could not be determined.

Sikorsky S-76B, N56RD at Vermilion 376A, April 17, 2012 (NTSB CEN12FA250)[11]

A Sikorsky S-76B was substantially damaged after ditching near an off-shore drilling rig in the Gulf of Mexico. The pilot and six passengers were not injured. The pilot reported that he was just over the landing pad at an off-shore drilling rig when the helicopter had a sudden loss of power. To avoid a hard landing on the deck, he attempted to abort the landing, but was unable to regain fly-away speed. After an emergency landing to the water, the pilot attempted to water-taxi in 5-foot seas when the tail boom partially separated from the fuselage. A rescue vessel quickly responded and all seven persons successfully evacuated with no injuries.

The helicopter wreckage was recovered April 25, 2012 and moved to Port Fourchon, La. On April 27, 2012 it was examined by Pratt and Whitney and Sikorsky technical representatives under NTSB supervision.

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[10] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

[11] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

The technical examination by the fuel control manufacturer, Hamilton Sundstrand, determined that a fuel control internal component (stepper motor) was operating intermittently and could have been perceived by the pilot as a minor engine power rollback. The report stated that the stepper motor fault could not account for the large power loss associated with the accident.

Bell 407, N1197 at Eugene Island 182A, May 30, 2014 (NTSB CEN14IA270)[12]

The pilot of a Bell 407 experienced a partial loss of engine power after lifting off from an offshore helideck. The pilot deployed the emergency flotation system and safely landed in the Gulf of Mexico. The pilot and five passengers were not injured. The helicopter was not damaged during the forced landing; however, it subsequently capsized and was substantially damaged during the recovery effort.

The pilot reported that after picking up into a hover, he applied forward cyclic to begin the takeoff. About the time that the helicopter reached the edge of the platform, the engine started to lose power. He nosed the helicopter forward to clear the platform. The low rotor speed horn came on and the warning light illuminated. The pilot inflated the floats, leveled the helicopter, and landed in the water. After shutting down the engine and securing the main rotor, the passengers and pilot exited the helicopter. The NTSB report does not indicate if the helicopter was recovered or that any tests were conducted on the engine.

Bell 206L-3, N54LP at Main Pass 107D, October 9, 2013 (NTSB CEN14FA004)[13]

A Bell 206L-3 was substantially damaged when it impacted the water shortly after takeoff from an offshore oil platform in the Gulf of Mexico. The commercial pilot was fatally injured and the three passengers were seriously injured. The pilot landed on the platform to effect a routine crew change. After landing, the pilot did not shut down the helicopter down and stayed at the controls with the main rotor turning until the crew change was complete. The wind was reported as calm.

About 1 to 2 minutes later, a witness observed the helicopter pull up into a 3 to 4-foot-high hover over the helipad and make a slight bearing change toward the east. He said at that point, everything was completely normal with the helicopter. The helicopter then moved forward and started to take off toward the east. The witness said as soon as the helicopter cleared the helipad's skirting, he saw a flash and a large (10-foot-high x 10-foot-wide) "poof" or "cloud" of white smoke come from directly under the main rotor blades near the exhaust section of the helicopter. This was followed by a loud, high-pitched, screeching noise, as if the engine were being revved up. The witness said this "poof" of smoke occurred when the helicopter was parallel to a flare boom that extended directly out from the platform and was positioned on the north side of the helipad. The witness said that after he saw the "poof" of smoke, the helicopter nosed over toward the water. The helicopter cleared the helipad's skirting and did not strike the flare boom as it descended.

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[12] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

[13] NTSB, Aviation Accident Database & Synopses, http://www.ntsb.gov/_layouts/ntsb.aviation/index.aspx

The witness said he did not see any methane gas being vented from the flare boom on the morning of the accident; however, he did see a large (size of an automobile) "methane cloud" coming from the flare boom the day before the accident between 12 and 5 pm. The methane cloud was located right where he saw the poof of white smoke on the day of the accident. The witness said he has seen methane being vented from the MP107D flare boom on several occasions. He said they vent "a lot of gas" several times a week.

The helicopter was recovered and examined by the NTSB. A visual examination of the engine revealed that it did not sustain much impact damage; however, several large holes were observed in the exhaust collector support stack. A hole was also observed in the cowling on the right side near the area of the support stack. Oil was in the bottom of the engine pan and the forward engine mounts were slightly bent. All engine fuel, oil and pneumatic lines, and b-nut fittings were tight and no leaks were observed.

The engine was removed and shipped to the manufacturer, where a tear down examination was conducted on under the supervision of an NTSB investigator.

The centrifugal compressor section was disassembled. The #1 and #2 bearings were examined and found to be free of any indications of distress. The compressor impellor vanes exhibited slight indications of rotational rubbing; however, no other indications of ingestion or other damage were noted.

The gearbox was disassembled. Examination of internal components did not reveal any obvious defects to gearing. The gearbox interior contained a large quantity of the magnesium gearbox case, corrosion deposits and material from the effects of sea water immersion and recovery operations.

The gas generator turbine and power turbine sections were disassembled. The Stage 1 turbine section was undamaged. The Stage 2 section revealed damage to the turbine disk blades, with one blade liberated from the blade root. All of the Stage 3 turbine disk blades were liberated at the blade roots. All of the Stage 4 turbine disk blades were damaged, with about 320 degrees of the blade shrouds detached. The blades did not breach the turbine cases. The turbine section stages were retained and are currently undergoing metallurgical examination.

2. *Analysis*

2.1 *Subtask C.4.5.1 – review and assess helideck construction standards*

General Description

This subtask requires (1) a review of current U.S. regulations and consensus standards (or lack thereof) that address the placement of methane vents or other sources of combustible gases in relation to helidecks; (2) a review of related international regulations and consensus standards that address placement of methane vents or other sources of combustible gases in relation to helidecks; and (3) the assessment and recommendation of industry best practices and safest technologies related to the placement of methane vents or other sources of combustible gases in relation to helidecks.

Methodology

A comprehensive, but not exhaustive, review of regulatory requirements and industry best practices was conducted. This included rules, regulations, standards, and guidance documents from the following organizations:

- International Standards Organization (ISO)
- International Civil Aviation Organization (ICAO)
- U.S. Federal Aviation Administration (FAA)
- UK Civil Aviation Authority (CAA)
- European Aviation Safety Agency (EASA)
- Transport Canada
- Civil Aviation Safety Authority of Australia (CASA)
- National Civil Aviation Agency (ANAC) of Brazil
- Instituto Nacional de Aviação Civil (INAC) of Angola
- Directorate General for Civil Aviation of Mexico
- Civil Aviation Authority (CAA) for Norway
- National Institute for Civil Aviation of Venezuela
- Bureau of Safety and Environmental Enforcement (BSEE)
- United States Coast Guard (USCG)
- Occupational Safety and Health Administration (OSHA)
- American Petroleum Institute (API)
- Helicopter Association International (HAI)
- Helicopter Safety Advisory Conference (HSAC)

An internet search was also conducted for images and descriptions of offshore facilities and mobile offshore drilling units (MODU) to ascertain layout locations of helidecks and flare facilities.

Results

An internet search on offshore fixed and floating platforms reveals wide variation in placement of helidecks, cranes, living accommodations and flare discharge locations. Images of representative platform configurations are provided in Appendix D.

U.S. Regulations and Consensus Standards

A comprehensive review of U.S. regulatory agencies and statutes revealed that there are no regulatory requirements or guidance promulgated by these agencies for mitigation of hazards posed by APG.

API 14J – Recommended Practice for Design and Hazards Analysis for Offshore Production Facilities

One of the principal consensus standards for helideck construction in the U.S. is API 14J. With respect to APG mitigation, this RP states the following in Section 5.9, about Flares and Vents:

The normal and abnormal releases of process vapors are collected and directed to safe locations by way of a facility's gas disposal systems. Both emergency relief and routine releases from a pressurized component or tank vent are potential fuel sources that should be removed from areas where ignition sources may exist. This is usually done by collecting these releases in a flare or vent system and directing the release to a safe location away from the production facility to allow for safe disposal of vapors by burning or dispersion. If liquids are expected in these releases, the flare or vent system will usually allow liquid removal prior to final discharge of the vapors. Flares are a source of ignition and are generally cantilevered off the main platform or located on a separate structure. In some cases a vertical flare tower on the main platform is used.

The permissible distance from the flare tip to various locations on the platform is determined from radiant heat calculations, or, if the flare has been extinguished, from gas dispersion calculations. Procedures for performing these calculations are contained in API RP 521. All wind velocities and directions should be considered in the design.

Hydrocarbon vents are a source of fuel. They may be located either on the main platform or on a separate structure. The minimum distance from the vent tip to potential sources of ignition is determined by dispersion calculations. It is also necessary to check radiant heat for flares, in case the vent is accidentally ignited. This latter calculation may control the location of the vent tip.

In most cases, the final discharge of a gas disposal system (gas outlet) should be an upward vertical or cantilevered pipe. The final discharge point should be located where the gas can be burned safely, or where it can be diluted with air to below the lower flammable limit (LFL) before reaching sources of ignition. The following should be considered in selecting a safe discharge point:

1. *Personnel safety.*

2. *The discharge volume and toxicity.*

3. ***The location in relation to other equipment, particularly fired vessels or other ignition sources, personnel quarters, fresh-air intake systems, helicopter and boat approaches, drilling derricks, other elevated structures and downwind platforms (emphasis added).***

4. *Prevailing wind direction.*

Vents should be designed so that accidental liquid carryover will not fall on hot surfaces or personnel areas. Local venting of non-process and low-volume sources (e.g., storage tank vents, surge tank vents, etc.) is acceptable provided that items 1 through 4 above are considered in the location of the discharge point.

Thus, API 14J requires an engineering analysis to consider the effects of both hot and cold gaseous discharges as well as radiant heat for helideck location. This would only apply to new designed facilities; legacy facilities are unaffected by these design guidelines.

API RP 2L – Recommended Practice for Planning, Designing, and Constructing Heliports for Fixed Offshore Platforms

Additional guidance for helideck design and construction is provided by API RP 2L. The current version (4th Edition) was published in 1996 and reaffirmed in 2012.

The current version of API RP 2L gives scant treatment to the consideration of hazards from APG. Under Section 4, Planning, the following guidance is given:

> *4.1.3 Design criteria presented herein include operational requirements, safety considerations, and* ***environmental aspects*** *which could affect the design of the heliport* ***(emphasis added)****;*
>
> *4.3.2 Location – Before final location of the heliport is selected, obstruction clearances, personnel safety, and* ***environmental conditions*** *as well as proximity of the approach-departure zone to* ***flammable materials****, engine exhaust, and cooler discharge should be considered* ***(emphasis added)****; and*
>
> *4.3.4 Orientation – Orientation of the heliport should be determined by the platform configuration, equipment arrangement, and prevailing wind.*

The intent of API 14J is reflected in the above recommendations from API RP 2L (2012) where it requires consideration of environmental conditions and proximity to flammable materials, which could be construed to include hazards posed by APG. Again, the current version of API RP 2L only applies to new design and not legacy helidecks.

To update the standard and address the issues of legacy helidecks which do not currently meet the standard, the API RP 2L (Fifth Edition) committee, in consortium with HSAC, has undertaken a comprehensive review of the recommended practice and divided it into three sections:

- API RP 2L-1 Planning and Designing Helidecks
- API RP 2L-2 Assessment, Upgrades, Modification, Replacement, and Marking of Existing Helidecks
- API RP 2L-3 Inspection, Maintenance, and Management of Offshore Helidecks

API RP 2L-1 Planning and Designing Helidecks (Final Draft)

The final draft of API RP 2L-1 contains more comprehensive treatment of the hazards to helidecks presented by APG. Section 4.3, Helideck Planning Considerations, provides the following guidance:

4.3.1 Location – Before the final location of the helideck is selected, obstruction clearances, personnel safety, and environmental conditions, as well as proximity of the obstacle free sector relative to flammable materials, hot and cold gas discharges, flare or vent booms, and cooler discharges should be considered. As illustrated in Figure 1, the helideck should be located to so that the TLOF and associated flight paths ***are as far as possible outside the influence of the hot and cold gas discharges (emphasis added)****.*

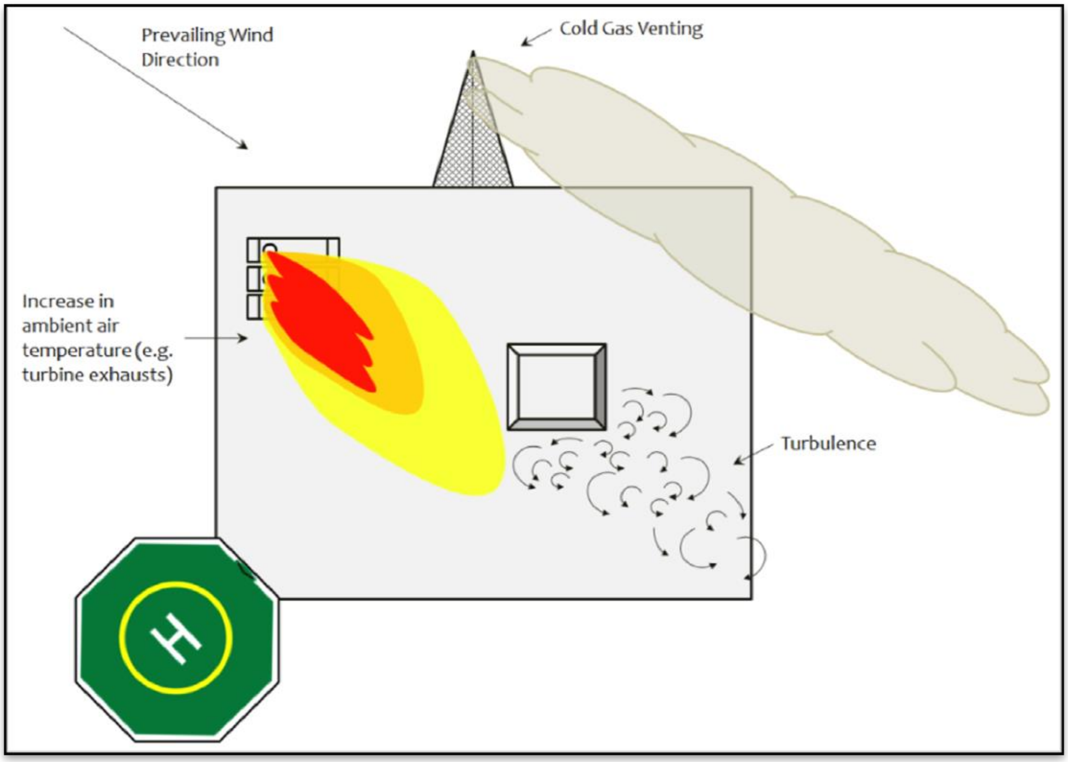

Figure 1: Helideck Orientation Based on Wind Direction/Exhaust Discharges

4.8 Hot Air, Raw Gas, and Hydrogen Sulfide (H2S) Discharge

Raw gas discharges or hot air discharges from compressors and cooling systems adjacent to helidecks may be hazardous to helicopter operations and can drastically affect helicopter performance and appropriate restrictions should be imposed on the use of the helideck where either of the above exists.

Hydrogen Sulfide (H2S) gas discharge in higher concentrations (300-500 ppm) can cause loss of consciousness within a few seconds.

When designing helidecks that have been identified to have any of the above conditions that may be hazardous to helicopter operations a visual warning system should be provided to alert pilots of the hazard. See 4.4 for additional guidance on

> *wind tunnel testing and/or Computational Fluid Dynamics (CFD) and 7.4 for status light guidance.*
>
> ***Sources of discharges should be located as far as practicable away from the helideck, flight path, and oriented so the typical prevailing wind will carry the discharges away from the helideck area (emphasis added)****.*
>
> *Note – Sniffers (generic term used to describe automated vapor detection devices) or other detection devices (infrared, etc.) may be used to detect these discharges and to automatically activate status lights (see Section 7.4) when discharges may present a hazard to flight operations.*

This revision of the API RP 2L applies to new design helidecks only and provides that the location of the helideck must take into consideration the hazards presented by APG (raw gases) and that the sources of discharge (flare, pressure operated relieve valves (PORV) decks, etc.) should be located as far as practicable from the helideck based on a computational fluid dynamic (CFD) or other gas dispersion modeling study.

Mention is made of Section 9.2, Weather Measuring Equipment, which suggests, in addition to a traditional wind sock directional indicator, that a manned facility for day VFR should be, as a minimum, equipped with a weather station that provides wind speed and direction, gust spread, temperature, barometric pressure, and a means to provide cloud ceiling height and prevailing visibility. For facilities operating under night VFR or any IFR operations, the measurement system must also provide the dew point value.

Where an existing manned facility is in close proximity to the planned new manned facility (‘close’ as determined by the regulatory authority having jurisdiction) it may deemed that the new facility does not have to provide the above equipment, provided those existing facilities which are equipped can share their information routinely to the new facilities. For these new facilities, a manual means of verifying and updating the visual elements of an observation, i.e. cloud amount and height of base, visibility and present weather, may be used.

API RP 2L-2 Assessment, Upgrades, Modification, Replacement, and Marking of Existing Helidecks (Draft)

The API RPL-2 draft concerning safety practices for legacy helidecks is in committee but is not well defined. At the time of this writing, the section concerning hazards posed by flares has not been addressed so is excluded from this report.

API RP 2L-3 Inspection, Maintenance, and Management of Offshore Helidecks (Draft)

A draft of this division of API RP 2L has not been completed. When drafted, it would be helpful if recommendations of operational procedures promulgated by this report would be incorporated in the operational guidance.

Helicopter Safety Advisory Conference (HSAC) Recommended Practice No. 92, Rev. 1 (2010): Helicopter Safety, Gas Venting Helideck/Heliport Operational Hazard Warning(s)/Procedures, Operations Near Gas Vent Booms

The HSAC RP No. 92 discusses the hazard presented by APG in very general terms:

> *Ignited flare booms can release a large volume of natural gas and create a hot intense heat with little time for the pilot to react. Likewise, un-ignited gas vents can release reasonably large volumes of methane gas under certain conditions. Thus, operations conducted in close proximity to un-ignited gas vents require precautions to prevent inadvertent ingestion of combustible gases by the helicopter engine(s). The following is recommended.*
>
> *1. Pilots*
>
> *(a) Gas will drift upwards and downwind of the vent. Plan the approach and takeoff to observe and avoid the area downwind or directly over the gas vent, remaining as far away as practicable from the open end of the vent boom.*
>
> *(b) Exercise caution when starting or landing on an offshore helideck when the deck is downwind of a gas vent.*
>
> *2. Oil Field Supervisors*
>
> *(a) Notify nearby helicopter operators and bases of the hazard for planned operations.*
>
> *(b) Wind socks or indicator should be clearly visible to provide upward indication for the pilot.*
>
> *(c) High volume large gas vents should have red rotating beacons installed to indicate when gas is venting.*

International Regulations and Guidance

ICAO Annex 14 to the Convention on International Civil Aviation, Aerodromes, Section II, Heliports

This international standard governs the construction and operation of aerodromes, including heliports. Section 3.3, Helidecks, and Section 3.4, Shipborne Heliports, provide very general guidance on the design of helidecks and refer the reader to the ICAO Heliport Manual for detailed guidance.

The ICAO Heliport Manual, Document 9261-AN/903 (1995) references three principle types of heliports: surface level, elevated, and helidecks which are located on offshore installations or ships. The manual enlarges upon some of the specifications in Annex 14, Volume II, and also provides additional guidance.

Section 1.4, Helidecks on Offshore Installations, advises that the location of the helideck is often a compromise between conflicting demands of basic design requirements, space limitations, and the process operational requirements of the installation. Statutory helideck design parameters may not often be possible to meet, but necessary restrictions by the authority having jurisdiction may be required, based upon tests such as metocean [14]data.

("Where the statutory helideck design parameters cannot be fully met, it may be necessary for restrictions to be imposed upon helicopter operations, based upon tests, for example in relation to wind velocity.") ICAO Heliport Manual, Document 9261-AN/903 (1995), 1.4.1.1.

Section 1.4.1.3 of the Heliport Manual provides some general guidance with respect to hazards presented by APG:

> *The helideck should be so located that the required clear approach and takeoff sector is available, making best use of the prevailing winds, and the FATO is least affected by structure-induced turbulence or by high temperatures and turbulence from the exhaust of gas turbines.*
>
> *The combined effects of airflow direction and turbulence, prevailing wind, and exhaust stack emissions should be determined for each installation and this information should be made available to the helicopter operator.*

Conversely, Section 1.4.3, Effects of Temperature Increases at Offshore Installations, gives extensive treatment to the hazards associated with flares and gas plumes. It provides guidance on hazard mitigation through design and location of the flare system:

> *1.4.3.2 Amongst the many effects of hot exhaust gases, one of the major aspects to be considered is the resulting modification of helicopter performance. Sudden increases in the environmental temperature over ambient can cause an abrupt loss of engine and rotor performance at a most critical stage of the helicopter operation.*
>
> *1.4.3.3 The emission of exhaust gas is usually in the form of a number of turbulent jets, which are injected into the complex turbulent flow that exists round the installation. The result is an interaction process which produces great variation in the rates of spreading and cooling individual plumes. The properties of the temperature field can be measured by wind tunnel model testing. However, because of the limited scope from a few scales of length, velocity and temperature, the results achieved can be used only as a guide to the type of phenomena that can exist in general, and to the relative levels of temperature that can be expected.*
>
> *1.4.3.4 As a plume develops, with an origin relatively clear of the helideck, the individual identity of the separate jets is gradually lost as the hot cloud mergers into one plume. Accordingly, the temperature is reduced and is more evenly*

---

[14] **Metocean:** wind speed, direction, gustiness, wind rose, wind spectrum, air temperature, humidity

> *distributed. By elevating the outlets sufficiently, the helideck can be kept clear of hot gas, but the resulting concentrated plume constitutes a considerable helicopter hazard. By lowering the outlet positions into the separated flow around the platform an increase in the dispersion of the plume can be obtained and the centerline temperature can be markedly reduced. However, the spread of the exhaust may become so great that almost all parts of the structure are contaminated under some wind conditions.* ***Quantitative tests thus become necessary to access the acceptability of such a design (emphasis added)****.*
> *1.4.3.5 Long, downward-directed outlets will remove most of the problems of plume interference with helicopter operations and should be satisfactory for the installation overall if suitable gas turbine and heating and ventilation intake positions can be made available. Even so, it is always advisable to test a specific configuration and associated gas turbine system with reference to particular sensitive locations. It is stressed that, when doing so, consideration must be given to the dynamic nature of the sensitive system, gas turbine intakes or the general environment, so that due regard may be taken of the strong fluctuations in temperature that may exist.*
>
> *1.4.3.6 Helicopter performance may also be seriously impaired as a result of the combined radiated and convected heat effects from flare plumes under certain wind conditions. In moderate or stronger winds, the radiated heat is rapidly dissipated and presents little problem for the helicopter pilot provided flight through the flare plume is avoided. However, in calm or light wind conditions the changes in temperature around the helideck can be very marked and localized and the helicopter may undergo a sudden unexpected loss of performance just as it is about to cross the edge of the helideck.*
>
> *1.4.3.7* ***Designers should, therefore, exercise great care in the location and elevation of flare towers in relation to helicopter operations (emphasis added)****.*

The guidance presented above is relatively dated as it was published in 1995 before modern computer-aided computational fluid dynamics (CFD) analysis was widely available as it is today. The guidance is mainly related to increased thermal hazards from outflows of the gas turbine compressors and power generation equipment but could be applicable to APG hazard mitigation as well.

ISO 19901-2:2014 – Petroleum and natural gas industries — Specific requirements for offshore structures — Part 3: Topsides structure

Section 9.5 provides guidance for helicopter landing facilities (helidecks). Section 9.5.1, General, requires that environmental conditions around the helideck, particularly wind flow and turbulence affected by adjacent structures, equipment and process plant, can influence the actions on, and controllability of, helicopters during landing and take-off and shall be considered. Conversely, Section 9.5.4, Reassessment of Existing Helidecks, allows for deviations from the standard if approved by the authority having jurisdiction but does not address environmental hazards, per se.

Conversely, Appendix A, Section A.9.5., Helicopter Landing Facilities (Helidecks) make reference to ICAO Annex 14, Aerodromes, Volume II — Heliports, AN 14-2, as promulgating the overall requirements for all aspects of helideck design, construction and equipment applicable to certain jurisdictions. In other cases, the requirements are usually addressed in class rules for floating or mobile structures such as the ABS Guide for the Class Notation Helicopter Decks and Facilities (HELIDK and HELIDK(SRF)). Otherwise, ISO 19901 addresses only structural consideration for helideck design.

Appendix A states that the selection of the platform layout should consider the effects of wind turbulence from items near the helideck, such as accommodation blocks, turbine exhausts, cranes and equipment. Thermal effects from hot and cold gases emitted by power generating or HVAC plants on the platform should also be considered. Design methods to model these effects can include wind tunnel (using small-scale physical models), or a CFD analysis.

UK Civil Aviation Authority (CAA) CAP 437 – Standards for Offshore Helicopter Landing Areas (2013)

Under the Air Navigation Order (ANO), UK helicopter operators are responsible for ensuring that helidecks to which they fly are ‘fit for purpose’. Installation and vessel owners, through their Safety Management Systems (SMS), also have the responsibility for ensuring their helidecks satisfy the helicopter operator’s requirements (CAP 437).

Section 2, Helideck Design Considerations – Environmental Effects, states:

> *The safety of helicopter flight operations can be seriously degraded by environmental effects that may be present around installations or vessels and their helidecks. The term “environmental effects” is used here to represent the effects of the installation or vessel and/or its systems and/or processes on the surrounding environment, which result in a degraded local environment in which the helicopter is expected to operate. These environmental effects are typified by structure-induced turbulence, turbulence and thermal effects caused by gas turbine exhausts, thermal effects of flares and diesel exhaust emissions,* ***and unburnt hydrocarbon gas emissions from cold flaring or****, more particularly, emergency blow-down systems* ***(emphasis added)****. It is almost inevitable that helidecks installed on the cramped topsides of offshore installations will suffer to some degree from one or more of these environmental effects, and* ***controls in the form of operational restrictions may be necessary in some cases (emphasis added)****. Such restrictions can be minimized by careful attention to the design and layout of the installation topsides and, in particular, the location of the helideck.*

Section 2.2, Helideck Design Guidance, incorporates two publications: CAA Paper 99004 and CAA Paper 2008/03, which are discussed below. Section 2.3.2 requires that all new-build offshore helidecks, modifications to existing topside arrangements which could potentially have an effect on the environmental conditions around an existing helideck, or helidecks where operational experience has highlighted potential airflow problems should be subjected to appropriate wind tunnel testing or Computational Fluid Dynamics (CFD) studies to establish the wind environment in which helicopters will be expected to operate.

Section 2.3.4 discusses requirements for "some form of exhaust plume indication" to be provided for use during helicopter operations. This visual indication system is associated with gas turbine exhaust and is reported in CAA Paper 2007/02, which suggests that design consideration be given to installation of an exhaust gas plume visualization system on installations having significant gas turbine exhaust plume problems as determined by operational or CFD analysis. The visualization system, such as injection of a "colored smoke" into the exhaust plume is used to aid in visual detection and avoidance of the plume by the aircraft pilot. It should be emphasized that this recommendation is not universal and is only suggested for installations that have identified plume-helideck operational issues.

Section 2.3.5 discusses that hazard of APG. While not providing guidance on the location of the flare exhaust, it discusses operational limitations during cold flaring of APG:

> *The maximum permissible concentration of hydrocarbon gas within the helicopter operating area is 10% Lower Flammable Limit (LFL). Concentrations above 10% LFL have the potential to cause helicopter engines to surge and/or flame out with the consequent risk to the helicopter and its passengers. It should also be appreciated that, in forming a potential source of ignition for flammable gas, the helicopter can pose a risk to the installation itself. It is considered unlikely that routine 'cold flaring' will present any significant risk, but the operation of emergency blow-down systems should be assumed to result in excessive gas concentrations. Installation operators should have in place a management system which ensures that all helicopters in the vicinity of any such releases are immediately advised to stay clear.*

The limitation concerning the maximum permissible APG concentration is discussed below. It is unclear from any of the documentation associated with CAP 437 as to how the statement "it is considered unlikely that routine 'cold flaring' will present any significant risk" was derived and there appears no engineering or scientific basis formally referenced for this statement in any supporting documentation for CAP 437.

Mention is made of Chapter 6, Helicopter Landing Areas – Miscellaneous Operational Standards, Section 4.2, Meteorological Observations, which strongly recommends that installations be provided with a means of providing meteorological data to the helicopter pilot, including wind speed and direction, air temperature and dew point, barometric pressure, cloud coverage and base height, and prevailing visibility.

UK CAA Paper 99004 – Research on Helideck Environmental Issues (2000)

This paper was a joint project between the CAA and the UK Health & Safety Executive (HSE) and focused on environmental hazards to helidecks. The prime contractor for the paper was BMT Fluid Mechanics, Limited. In 1995, an accident occurred on the Claymore Accommodation Platform which, although it did not involve any fatalities or serious injuries, highlighted the need to reassess the environmental hazards to helicopters operating in close proximity to offshore installations. The features of the accident gave rise to concern related to an uncontrollable descent immediately above the landing area, resulting in a heavy [*hard*] landing and extensive damage to the helicopter. The precise cause was not determined, but it was most probable that the flying pilot inadvertently flew into a plume of combustion products from a gas turbine unit operating on the bridge-linked production platform. As a result of this mishap and others, the UK CAA and HSE commissioned the study on environmental hazards to offshore helicopter operations which promulgated the findings and recommendations in CAA Paper 99004 and its progeny, CAA Paper 2008/03 and as incorporated in CAP 437.

While CAA Paper 99004 addresses mainly mechanical wind turbulence and hot exhaust gas temperature plumes which may cause adverse effects in the flying qualities and engine performance, respectively, it does provide some guidance concerning the hazard from APG:

> *4.1.5 Release of Process Gas*
>
> *There are occasions in the operating life of a platform when gas from the process streams will be vented to atmosphere. Accidental releases may also occur. The aerodynamic behavior of the released gas will depend upon its density, temperature, venting momentum and location on the platform.*
>
> *Clearly, these are circumstances requiring extreme caution for all platform operations since the release offers the potential for fire or explosion. That said, the extent of flammable/explosive conditions are often defined during the Safety Case process and the principles of entrainment of air and dilution are analogous to that for hot plumes. Away from the immediate area of the source the resulting plume or cloud will be carried in the direction of, and with the speed of, the local wind. The hazard due to the ingestion of hydrocarbon gas mixtures into a helicopter engine is discussed in Section 5.3.*
>
> *4.1.6 Flared Gas*
>
> *Platforms normally have flare towers, comprising tall or long cantilevered structures designed to remove a source of released gas as far away from the platform as is practicable. The flare may also be the location for the venting of unburned gas (see Section 4.1.5), but, specifically, it is designed to burn off excess gas. The Energy Act of 1985 calls for gas conservation so that flaring is essentially for use only in the event of an emergency. (Note – this is not true on the U.S. OCS).*
>
> *Flares are, of course, highly visible, though the thermal plume beyond the flame is not. The combustion products beyond the flame tip are hot (many hundreds of degrees C), but the process of mixing and cooling is aggressive and the plume dilutes and cools whilst moving downwind much like any other turbulent plume. The hot gas plume from the flare presents a hazard similar to the gas turbine exhausts plume, but it has the advantage of usually being more visible to pilots.*

One reason for the flare tip to be well removed from the platform is to avoid radiant heat from the flame affecting personnel, equipment and the helideck. This is considered and dealt with during the platform design phase.

Concerning guidance on location of the flare or emergency blowdown system from the helideck, Section 4.2.4 and 4.2.5 discuss this in general terms:

4.2.4 Flare Location

The flare tower (vertical structure) or flare boom (inclined lattice structure) is designed to remove the flare tip a sufficient distance from the platform to ensure that the radiated heat from the flame is not a problem on the platform itself. The flare boom is located at the process end of the platform and the initial design requirement is to keep temperatures at acceptable levels in the associated working areas. The helideck is, necessarily, considerably more distant from the flare and special considerations for radiant heat should not be required.

As far as the hot plume emitted by the flame is concerned, it will generally be at sufficient elevation to be well clear of the helideck. During approach and take-off, if the flare is alight the plume alignment will be downwind of the tip and generally higher. The plume may thus be avoidable by exercising precautions in flight, supported by information on flare plume characteristics derived at the design assessment stage.

***From the standpoint of design, per se, relatively little can be done to make the flare more helicopter friendly (emphasis added)**.*

4.2.5 Gas Blow-Down Systems

In the event of process upset, there may be an operational requirement to discharge hydrocarbons to the atmosphere. Generally it will be preferable to burn the released gas in a controlled fashion and so the blow-down system is led to the flare boom.

*Significant gas releases are fortunately rare events, with just 16 major releases reported in 1996/97 under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995. **If the discharged gases are released unburned then a significant hazard of mixtures which are potentially flammable can exist. From the standpoint of helicopter operations, this is a situation which can only be avoided by information and communication with the platform (emphasis added)**. Such procedures should logically form part of the platform operational Safety Case.*

UK CAA Paper 2008/03 – Helideck Design Considerations – Environmental Effects (2009)

Although both CAA Paper 99004 and 2008/03 are incorporated by reference in CAP 437, the latter is an update of the former and gives specific treatment to location of flare vents and hazards presented by APG:

> *3.7 Cold Flaring and Rapid Blow-Down Systems*
>
> *Hydrocarbon gas can be released from the production platform process or from drilling rigs at various times. It is important to ensure that a helicopter cannot fly into a cloud of hydrocarbon gas because;*
>
> - *concentrations above 10% of Lower Flammable Limit (LFL) might cause the helicopter engine to surge or flameout with consequent risk to the helicopter, and*
> - *the helicopter poses a risk to the offshore installation because it is a potential ignition source for the hydrocarbon gas.*
>
> ***Consideration therefore needs to be given to ensuring that gas release points are as remote as possible from the helideck and helicopter flight path, and that any unforeseen gas releases activate the helideck status lights (flashing red). Planned gas releases should only occur when helicopters are not in the area (emphasis added)****.*
>
> *The blow-down system on a production platform depressurizes the process system releasing the hydrocarbon gas. It will normally be designed to reduce the pressure to half, or to 7 bar, in 15 minutes (the API standard). For a large offshore installation this might require the release of 50 tonnes of gas or more. Once down to this target pressure in 15 minutes or less, the remainder of the gas will continue to be released from the system. A blow-down may be automatically triggered by the detection of a dangerous condition in the production process. Alternatively it may be triggered manually. The blow-down system should have venting points that are as remote as possible from the helideck and, in prevailing winds, downwind of the helideck. It is common to have this vent on the flare boom, and this will normally be a good location.*
>
> ***However, it should be noted that dilution of the gas to 10% LFL may not occur until the plume is a considerable distance from the venting point. This distance could be anywhere between 200m – 500m depending on vent size, venting rate and wind speed (emphasis added).***
>
> *Drilling rigs often have 'poor-boy degassers' which are used to release gas while circulating a well, but a drilling rig is unlikely to release any significant quantities of gas without warning, unless there is a sudden major crisis such as a blow-out. As with production platforms,* ***it is unlikely to be possible to locate the helideck sufficiently distant from the potential gas sources to guarantee 10%***

> ***LFL or less, (emphasis added)*** *and so the rig should not accept helicopter flights when well circulation activity is going on, or when there are problems down the well.* ***Helideck status lights should be connected to the appropriate gas detection systems and automatically initiated (emphasis added)****.*

Discussion on the 10% lower flammability limits (LFL) is presented below on the section on methane ingestion effects on helicopter turboshaft engines.

Lastly, Section 3.9, Multiple Platform Configurations, requires the consideration of the effects of adjacent facilities, whether they are interconnected or not, on aerodynamics, hot gasses, etc., on the other platform's helideck.

UK HSE Helideck Design Guideline (No Date)

As a supplement to the CAA CAP 437 regulations, the UK Health & Safety Executive (HSE) has issued a helideck design guideline. Recommendation 10.3 (i) in CAA Paper 99004 discussed above was the main starting point for the guidelines along with an increasing number of non-conformities found during helideck inspections.

The helideck design guidelines are designed to be used in conjunction with the latest edition of CAP 437 and the UK Offshore Operators Association Guidelines for Management of Offshore Helideck Operations which are considered companion documents.

Section 10.4.6, Temperature Rise Due to Hot Exhausts, recommends against the long, downward-directed outlets for gas turbine exhaust gases (and by extension, APG discharges) promulgated by Section 1.4.3.5 of ICAO Annex 14, Volume II. The helideck design guide states:

> *For certain wind directions the hot gas plumes from the exhausts will be carried by the wind directly across the helideck. The hot gas plume mixes with the ambient air and the mixing increases the size of the plume, and reduces the temperature (by dilution).*
>
> *In the past, some platforms were fitted with downward facing exhausts so that the hot exhaust gases were initially directed down towards the sea surface.* ***This arrangement is not recommended because the hot plume can rise and disperse in an unpredictable way, particularly in light wind conditions (emphasis added).***

Concerning hazards from APG flares and emergency blowdown systems, the helideck design guidelines incorporated verbatim Section 3.7, Cold Flaring and Rapid Blow-Down Systems, of CAA Paper 2008/03 discussed above.

NORSOK C004 Ed. 2 – Helicopter Decks on Offshore Installations (2015)

The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Furthermore, NORSOK standards are as far as possible intended to replace oil company specifications and serve as references in the authorities' regulations.

The NORSOK helideck standard is based on practical experiences accumulated from helicopter operations on the Norwegian continental shelf. Relevant information was provided by oil companies, helicopter operators, and The Foundation for Scientific and Industrial Research at The Norwegian University of Science and Technology (SINTEF). A joint industry project on helideck safety was completed in January 2000. The main conclusions and recommendations are included in NORSOK C004 and the standard focuses on a rational selection of design criteria and other measures, to increase safety and flight regularity in connection with offshore helicopter deck operations.[15]

Section 5.1 requires a CFD analysis or wind tunnel test to be performed for initial design and for any substantial modifications to the helideck. Any conclusions or recommendations shall verify and document that the helideck has been given an optimal location on the offshore installation. Any possible hazards or restrictions on helicopter operations are to be identified.

Section 5.4 provides guidance on the mitigation of hot gas turbulence with respect to flare and gas turbine exhaust outflow but not to APG specifically:

> *Offshore installations will normally contain a variety of systems and processes that will emit hot air flows, typically generated by turbine generators, diesel engines and flare(s). Hot air flows from these systems may create turbulence and other thermal effects that may severely affect helicopter operations, unless adequate risk reducing measures are taken at the design stage.*
>
> *Hot air flow, combined with a sudden change in air temperature, may have the following two major effects on the helicopter performance:*
>
> - possible momentary stalling of helicopter engines due to sudden air density changes through the turbine compressors;
> - significant reduced helicopter lift capacity.
>
> *These risks can be controlled by either proper design, which should be the main priority, or* ***by operational measures that may involve certain helicopter flight limitations [emphasis added]****. The risk varies with helicopter type, and the risk level increases with large temperature gradients in the flight path.*

The standard gives three methods for determining the risk of thermal gradients to helicopter operations. Method 1 requires a CFD analysis for designing new helidecks and requires that the free airspace above the helideck not be exposed to a temperature increase of more than 2°C (iso-contour from the CFD). The free airspace is defined as a height above the helideck corresponding to approximately 10 meters (33 feet) plus the skid or wheels-to-rotor height plus one rotor diameter. In situations where Method 1 is deemed impossible, unpractical or

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[15] NORSOK standard C-004, Helicopter deck on offshore installations, Rev. 2, May 2015; http://www.standard.no/pagefiles/1323/c-004.pdf

noncompliant, two other methods are provided. Method 2 is empirically derived and bases on a plot of minimum height of gas release versus distance from the center of the helideck.

Method 3 is of special interest because it may be applied to legacy helidecks to determine the risk from thermal gradients. This approach and methodology was developed in close cooperation with offshore helicopter operators. The method is described in a document "*A method utilizing Computational Fluid Dynamics (CFD) codes for determination of acceptable risk level for offshore helicopter flight operation with respect to hot gas emission from turbine exhaust outlets"* which is available from NORSOK. This procedure also requires the location of the 2°C isotherm above the helideck.

Examples of CFD models of the isothermic dispersion of hot gasses over helidecks are shown in Figures 2 and 3 below.

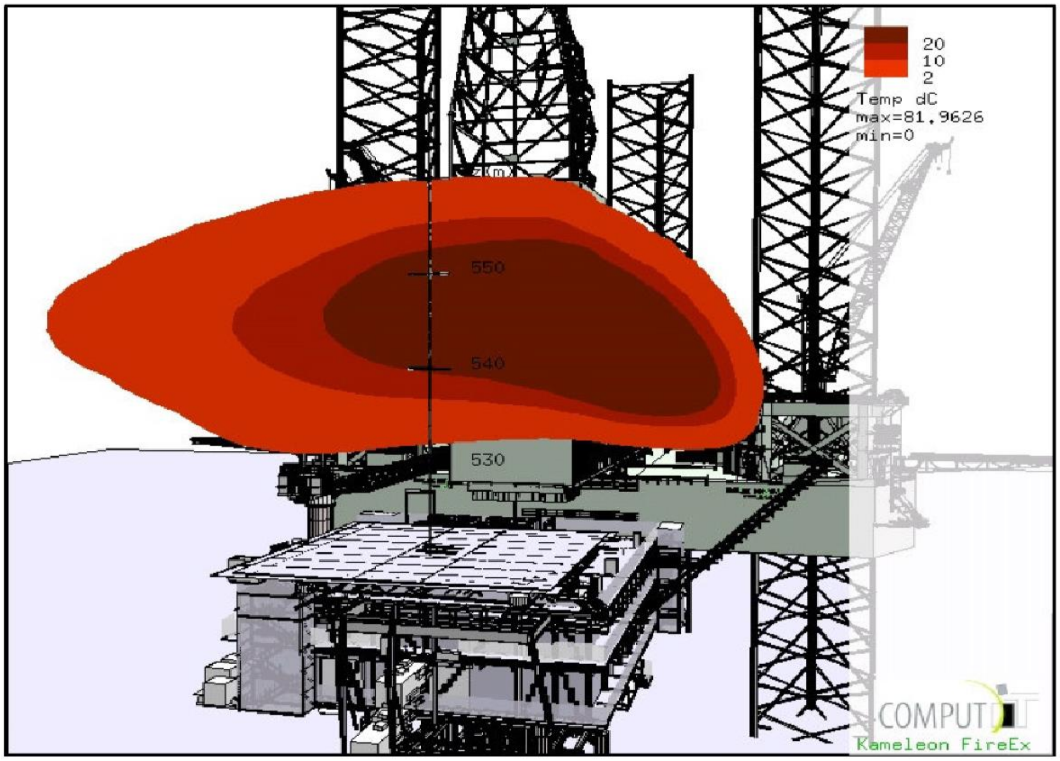

Figure 2: CFD Model, Isothermic Dispersion 1

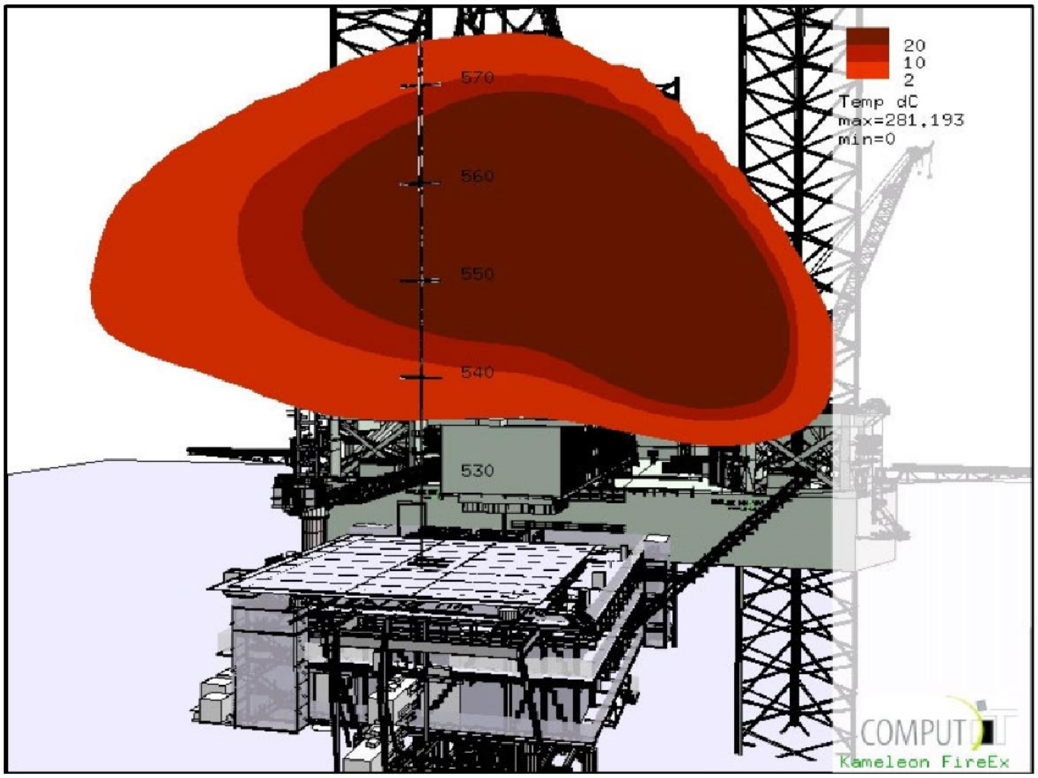

Figure 3: CFD Model, Isothermic Dispersion 2

Section 5.5, Hydrocarbon gas emission, is a new section not included in the first edition of the standard (2004):

> *Cold flares and emergency blow down (*sic*) systems are a potential source of hazard that helideck designers should be aware of. Concentration of hydrocarbon gas in the helicopter operational environment may be a potential danger to both the helicopter and the offshore installation. The helicopter itself may be a potential ignition source endangering the offshore installation;* ***while a hydrocarbon concentration above 10% low flammability limit (LFL) may cause engine surge and flameout endangering the helicopter [emphasis added]****. Helicopter operations will be immediately stopped should such conditions occur*.

While the language of Section 5.5 is an improvement over the previous version in that it recognizes the hazard to flight operations posed by APG, it does not give any guidance on how “helicopter operations will be immediately stopped” if the gas concentration over the helideck should reach the 10 percent LFL limit. This mandate would require a CFD gas dispersion model of the facility at the least favorable wind conditions (Figure 4) to quantify the risk, and that point and area gas detection equipment be installed to provide the operator warning of the hazardous conditions in time to alert the flight crew prior to approach or departure. Examples of CFD gas dispersion models are shown in Figures 5-7 below.

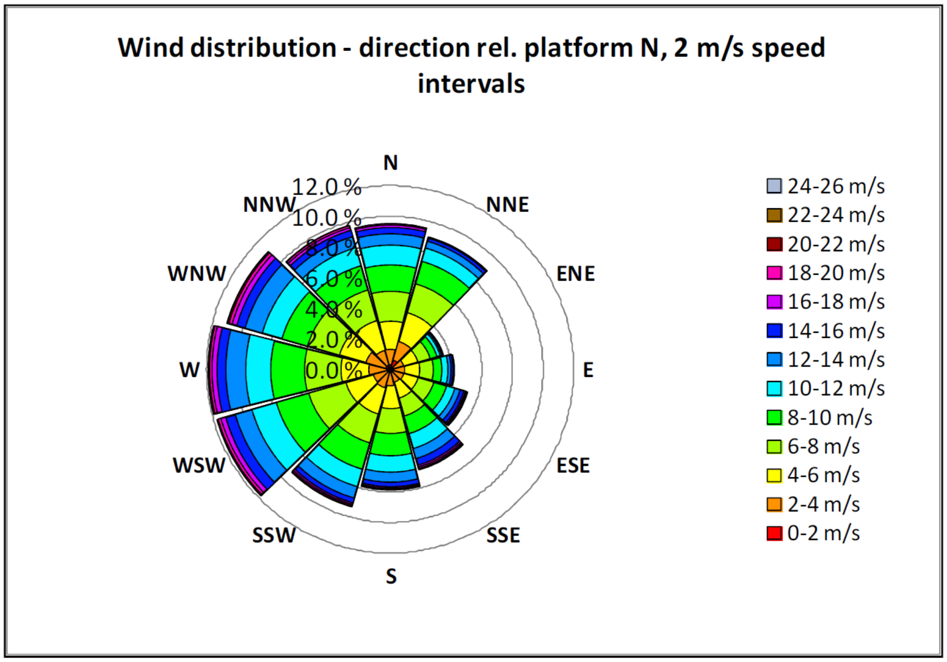

Figure 4: Platform Wind Distribution with Least Favorable Conditions

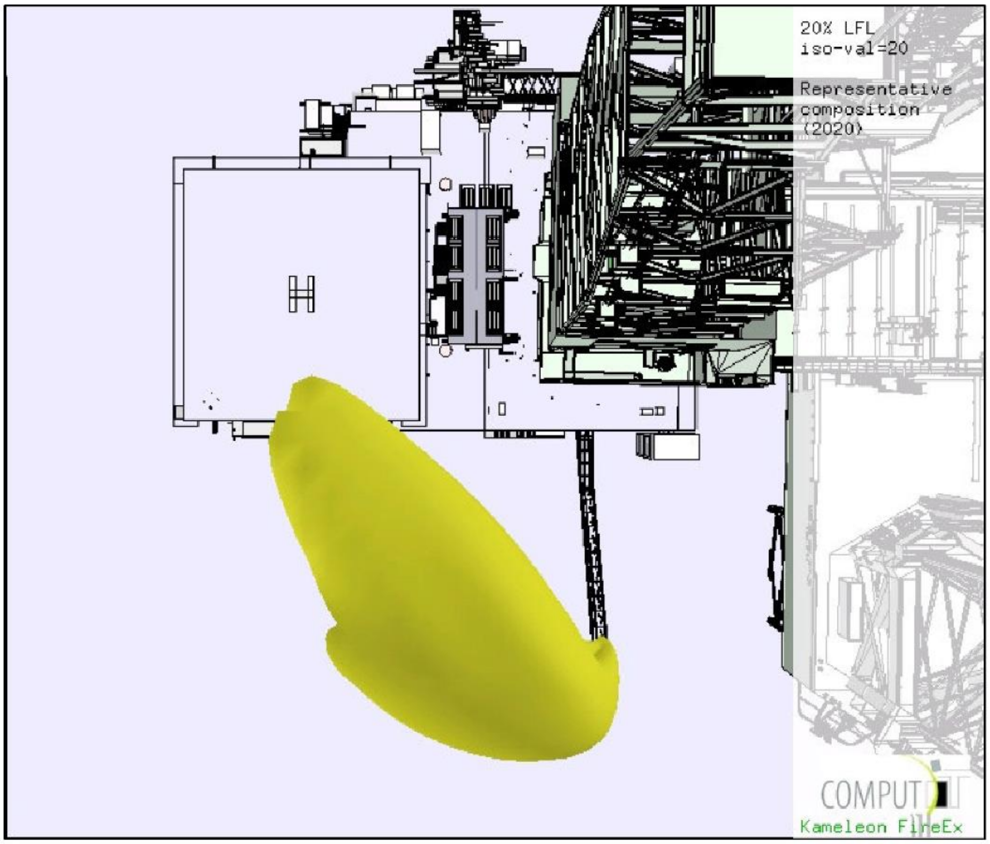

Figure 5: CFD Gas Dispersion Model Example 1

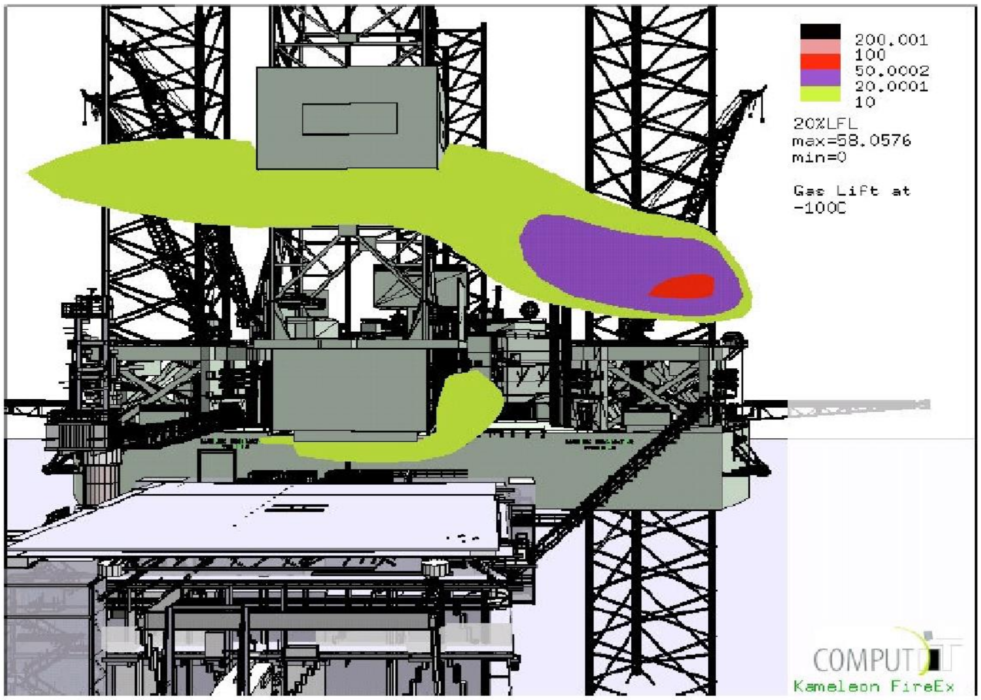

Figure 6: CFD Gas Dispersion Model Example 2

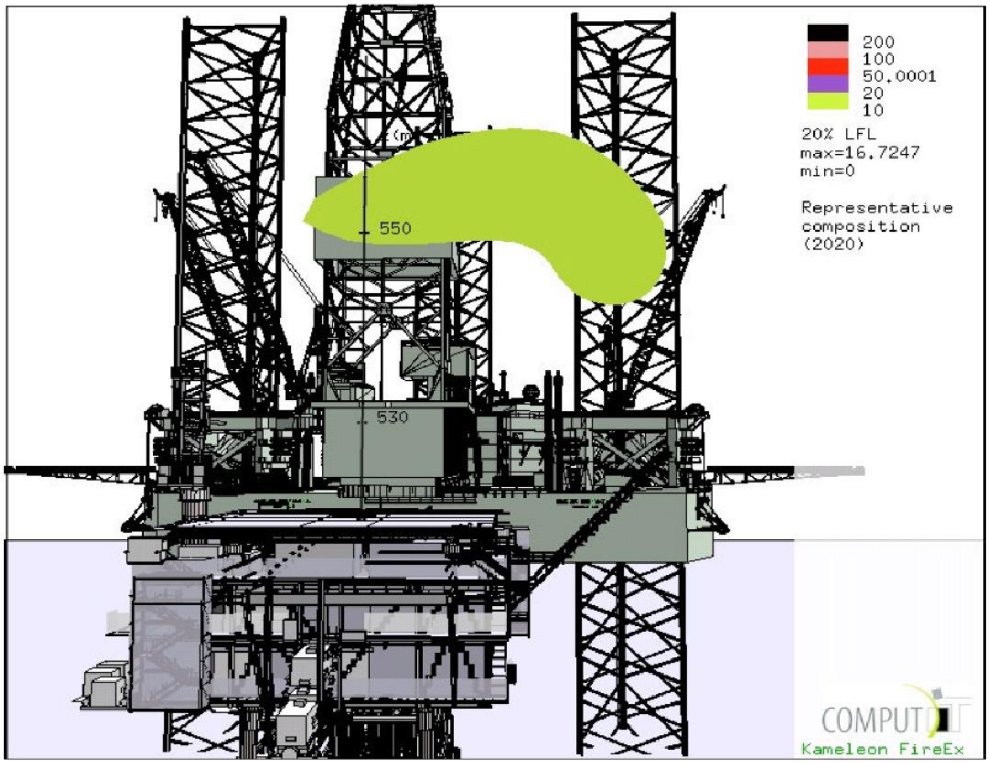

Figure 7: CFD Gas Dispersion Model Example 3

Moreover, the 10% LFL APG limitation is more likely than not lifted verbatim from the UK CAP 437 document discussed above.

Mention is made of the requirement for a Helideck Monitoring System (HMS). The NORSOK C004 HMS requirements are:

> *A helideck monitoring system for recording of relevant meteorological data shall be provided. Such data shall include wind speed, wind direction, barometric pressure, visibility, precipitation and air temperature close to the helideck, see NORSOK N-002.*
>
> *Helideck wind shall be measured in the 150° LOS (limited obstacle sector), approximately 10-30 meters above and adjacent to the helideck. Area wind shall be measured in a position with undisturbed airflow. Floating installations, production, drilling and storage vessels shall be equipped with an additional monitoring system. The system shall provide information regarding the helideck's motion characteristics with respect to roll, pitch and average heave rate. The sensor(s) shall be located close to the helideck centre.*
>
> *All information shall be numerically displayed, both in the central control room and the HTCC, for easy communication with helicopters in flight and helicopter land base operations.*
>
> *The accuracy of the system shall be checked and verified whenever deemed necessary, but at least once every 3 years. The manufacturer's procedures shall be followed.*

2.2 *Subtask C.4.5.2 (a) – conduct technical analysis*

General Description

This subtask consists of a number of detailed identification and sub-analysis tasks which are sub-numbered for the purposes of clarity.

Subtask C.4.5.2 (a) – identify and list each regulation that addresses venting and flaring of methane on OCS facilities under BSEE jurisdiction, highlighting any regulation that favors one method over the other.

Methodology

Air emissions in the U.S. are regulated under 42 U.S.C. 7401, et seq. as codified in 40 C.F.R. Subchapter C, Parts 50-97, referred to as the Clean Air Act. The EPA has jurisdiction under the Act out to the limits of the 200 nautical mile Exclusive Economic Zone (EEZ) which would include the Continental United States (CONUS) OCS. A comprehensive review of U.S. regulations under the Clean Air Act and other EPA regulations and guidelines was conducted. A detailed discussion with the EPA Coordinator for Air Permitting in Region 6 (U.S. Gulf Coast) was conducted concerning permitting requirements for facilities on the OCS.

Results

The research for this report yielded no regulatory restrictions under U.S. law concerning the flaring or venting of methane or other APG.

The EPA promulgates the National Ambient Air Quality Standards (NAAQS) by authority of the Clean Air Act. The standards cover a number of pollutant and greenhouse gases, including, sulfur oxides (SO_x), carbon monoxide (CO), other oxides such as ozone (O_3), Particulate Matter (PM_x), Volatile Organic Compounds (VOC), and lead (Pb). The constituents of APG, including methane, or its byproduct from hot flaring, CO_2, are not regulated by NAAQS.

Offshore facilities fall under the EPA's Prevention of Significant Deterioration (PSD) [of air quality] rules which apply to new major sources or major modifications at existing sources for pollutants where the area the source is located is in attainment or unclassifiable with the NAAQS. The term "major source" means any stationary source or group of stationary sources located within a contiguous area and under common control that emits or has the potential to emit, considering controls, in the aggregate, 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants. Conversely, a major modification means any physical change in, or change in the method of operation of, a major source which increases the actual emissions of any hazardous air pollutant emitted by such source by more than a *de minimis*[16] amount or which results in the emission of any hazardous air pollutant not previously emitted by more than a *de minimis* amount. Lastly, Congress has codified hazardous air pollutants in a Hazardous Air Pollutants list[17]; none of the constituents of APG or the combustion byproduct CO_2 are listed as hazardous air pollutants. Even if the PSD were to apply to offshore facilities, the regulation requires:

1. *Installation of the "Best Available Control Technology (BACT)";*
2. *An air quality analysis;*
3. *An additional impacts analysis; and*
4. *Public participation.*

BACT is an emissions limitation which is based on the maximum degree of control that can be achieved. It is a case-by-case decision that considers energy, environmental, and economic impact. BACT can be add-on control equipment or modification of the production processes or methods. This includes fuel cleaning or treatment and innovative fuel combustion techniques. BACT may be a design, equipment, work practice, or operational standard if imposition of an emissions standard is infeasible. BACT analysis is discussed below under Subtask C.4.5.3 – Monitoring and Warning Systems.

40 C.F.R. Part 98, Mandatory Greenhouse Gas Reporting, Subpart W, Petroleum and Natural Gas Systems, applies to offshore facilities. 40 C.F.R. 98.230 (a) (1) defines an offshore source as:

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[16] "*de minimis*-very small amounts of hazardous waste that are discharged to wastewater treatment facilities and thus, are exempt from the mixture rule" EPA Resource Conservation and Recovery Act Manual,, downloaded from http://www2.epa.gov/sites/production/files/2015-07/documents/rom.pdf:

[17] 42 USC 7412(b) List of Pollutants

> *Offshore petroleum and natural gas production is any platform structure, affixed temporarily or permanently to offshore submerged lands, that houses equipment to extract hydrocarbons from the ocean or lake floor and that processes and/or transfers such hydrocarbons to storage, transport vessels, or onshore. In addition, offshore production includes secondary platform structures connected to the platform structure via walkways, storage tanks associated with the platform structure and floating production and storage offloading equipment (FPSO). This source category does not include reporting of emissions from offshore drilling and exploration that is not conducted on production platforms;*

MODU's are generally exempt from the reporting requirements.

40 C.F.R. § 98.231, Reporting Threshold, section (b) requires offshore petroleum and natural gas production facilities to report carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions from equipment leaks, vented emission, and flare emission source types as identified in the data collection and emissions estimation study conducted by the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE[18]) in compliance with 30 C.F.R. §250.302 through 304. Offshore platforms do not need to report portable emissions. The current (2014) 30 C.F.R. §250 does not contain sections 250.302 through 304.

2.3 *Subtask C.4.5.2 (b) – identify and list each helicopter (make, model, and engine) used on OCS facilities under BSEE jurisdiction.*

Methodology

An internet search of helicopter companies operating under 14 C.F.R, Part 135 generally engaged in offshore oil and gas exploration and production was made to determine the representative makes and models of helicopters operating on the OCS. Moreover, the experience of the aviation safety analysts with extensive experience in offshore helicopter operations was used.

Results

There were seven (7) major airframe manufacturers producing 56 different models and their variants. Conversely, five (5) engine manufacturers were identified which were producing 41 turboshaft engine models and their variants.

A complete listing of make, model, engine(s) and specifications, including shaft horsepower, maximum gross takeoff weight (MGTOW), range, and crew and passenger capacities is provided in Appendix E.

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[18] The Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE.) was replaced by the Bureau of Safety and Environmental Enforcement (BSEE) on October 1, 2011 as part of a major reorganization of the Department of the Interior's offshore regulatory structure.

2.4 *Subtask C.4.5.2 (c) – (1) determine the vapor density for each flammable gas (lighter or heavier than air) to determine how the placement of vents would affect helicopter operations; and (2) determine the flammability limits for each flammable gas to determine the effect on helicopter operations.*

Methodology

A byproduct of offshore hydrocarbon production and processing is associated petroleum gas (APG). APG is a form of natural gas which is found in geophysical hydrocarbon deposits, either dissolved in the liquid hydrocarbons or as a free gas above the liquid in the reservoir. For safety reasons, offshore installations are equipped with a flare boom or stack to perform a controlled release of APG into the atmosphere (known as “venting” or “cold flaring”) or to perform a controlled burn of the APG (known as “flaring”), if any or all of the APG constituent gasses cannot be recovered or recycled for economic or practical reasons. During flaring, the APG are combined with steam and/or air, and burnt off in the flare system to produce water vapor and carbon dioxide which produces a visible flame and forms a non-explosive vapor cloud. If the flare is not ignited (cold flaring), the APG forms an invisible vapor cloud which may be flammable, depending upon its stoichiometric concentration with the air.

Most process facilities either use APG as a fuel gas for compressor turbines, electrical power generation, or other utilities, or attempt to separate APG into its constituent gases as an economic product and to reduce their potential to emit pollutants as part of an air quality program. The APG is separated from the liquid hydrocarbons through flash or phase separation, then extracted through a fractionation train using a deethanizer, depropanizer, and debutanizer, leaving methane as the last constituent gas of the APG. If this methane is not used as a fuel gas, it is sent to the off-gas incinerator (flare). Therefore, methane makes up more than 90 percent of the APG released by the flare system. Figures 8 and 9 represent the APG elimination process.

Since methane makes up the bulk of APG, to simplify the analysis, only methane need be considered as a combustible gas hazard to rotorcraft.

Physical data for the constituents of APG was found in the Chemistry Handbook published by the National Institute for Standards and Technology (NIST) Materials Measurement Laboratory.

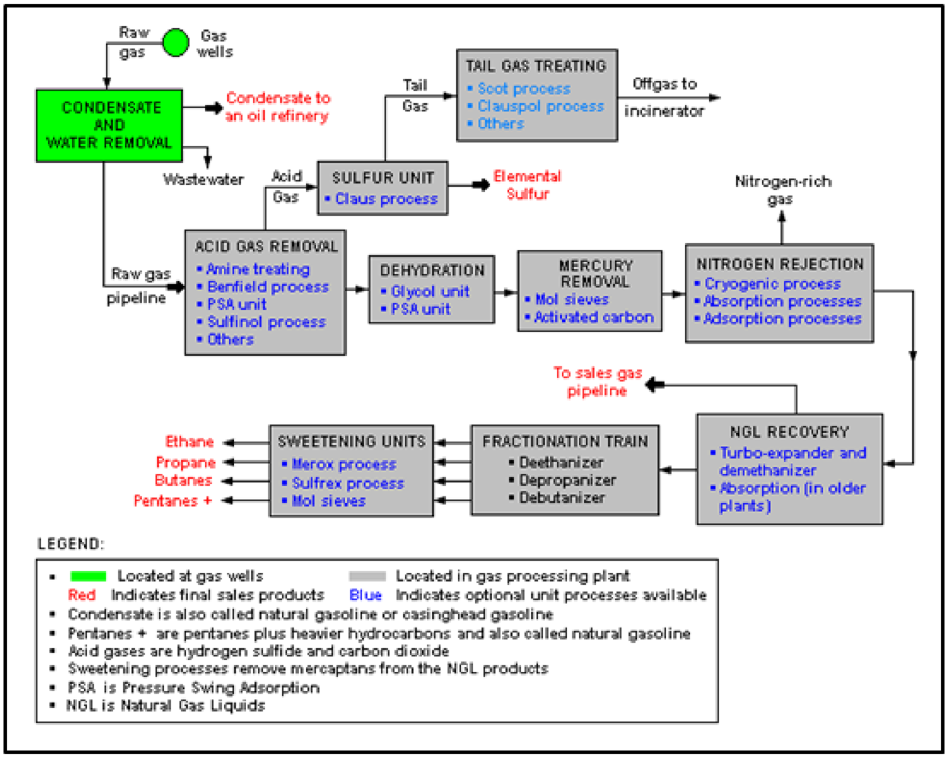

Figure 8: APG Dethanization Process

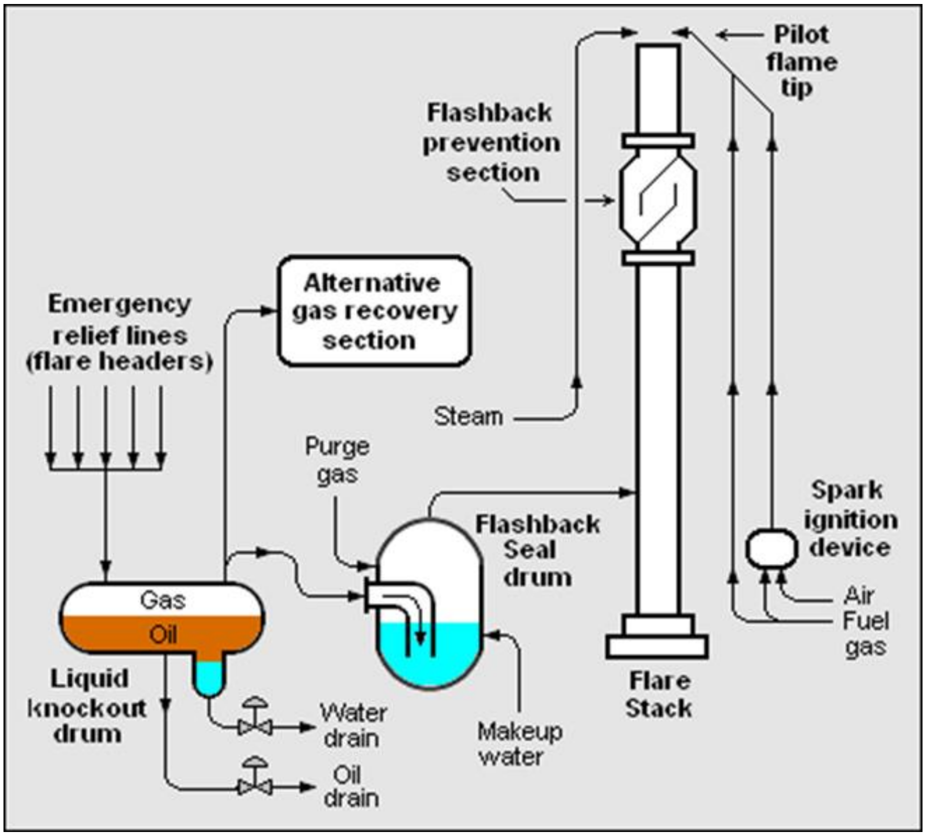

Figure 9: Off-Gas Incinerator Process (Flare)

Results

Table 1 presents the hydrocarbon constituents of APG and their associated physical properties.

	APPOXIMATE APG COMPOSITION AND PHYSICAL PROPERTIES							
Common Name	Molecular Formula	Volume Fraction (% APG)	Molar Mass (g-mol^{-1})	Flammability Limits (%Vol)	Boiling Point (°C)	Autoignition Temperature (°C)	High Heat Value (kJ-mol^{-1})	Ignition Energy (mJ)
Methane	CH_4	81.0	16	4.4-17	-161.5	537	889	0.21
Ethane	C_2H_6	5.5	30	2.9-13	-88.5	472	1,560	0.22
Propane	C_3H_8	6.6	44	2.4-9.5	-42.2	540	2,220	0.26
Butane	C_4H_{10}	4.0*	58	1.8-8.4	-1.0	288	2,877	0.25
Isobutane	C_4H_{10}	4.0*	58	1.4-8.3	-13.0	460	2,877	0.26
Pentane	C_5H_{12}	1.4*	72	1.4-8.3	35.9	260	3,507	0.24
Isopentane	C_5H_{12}	1.4*	72	1.4-8.3	27.8	420	3,507	0.21
Hydrogen Sulfide	H_2S	Variable	34	4.3-46	-60.4	232	512	0.068

Table 1: Approximate APG Composition and Physical Properties

In general, the combustible gases of concern are the C_1 through C_5 series hydrocarbons and their common isomers which are normally flammable gases at atmospheric standard temperatures and pressures. Pentane is usually a small constituent of APG but is a flammable gas at flare stack temperatures. The common name of the compound is the one generally used and understood in the offshore industry as opposed to the International Union for Pure and Applied Chemistry (IUPAC) name; for example, the IUPAC name for water is dihydrogen monoxide and methylpropane for isobutane.

The molar mass (gram molecular mass) is the weight of one molecule of the compound determined by summing the molecular mass of each constituent atom. The flammability limits are the upper and lower concentrations in normoxic air at 25°C at which the compound would ignite and or explode when exposed to a competent ignition source, such as a flame or spark. The boiling point is the temperature at which the vapor pressure of the liquid equals the atmospheric pressure surrounding the liquid and the liquid changes into a vapor. At any temperature above the boiling point, the compound is a gas. The autoignition temperature is the lowest temperature at which the compound will spontaneously ignite in normoxic air without a competent ignition source. This temperature is required to supply the activation energy needed for combustion through adiabatic heating such as compression in a turboshaft engine. The high heat value is the theoretical specific energy content of the compound that would be released on combustion. Lastly, the minimum ignition energy (MIE) is the minimum amount of energy required to ignite a flammable vapor or gas cloud, such as by an electrostatic discharge.

For hydrocarbons C_1 to C_5, there is a direct relationship between the gram molecular weight and the boiling point and heat energy values. Conversely, there is an inverse relationship between the gram molecular weight and the flammability limits and autoignition temperature. This is a predictable result from the hydrogen bond energy on the carbon atoms which is well known in hydrocarbon reactions. Note that isomers can affect a large increase in the autoignition temperature of the compound.

Air has an average gram molecular weight of 29 g-mol^{-1} at standard temperature and pressure. Thus, any compound with a molar weight larger than this value will be heavier than air. **Methane, with a value of 16 g-mol^{-1} is the only compound lighter than air and thus has profound consequences when considering the effects of turboshaft hydrocarbon gas ingestion.**

The average minimum ignition energy (MIE) for APG is approximately 0.25 millijoules (mJ). This is extremely small ignition energy. For example, the static electricity generated by a person walking across an electrostatically-charged carpet is about 10 mJ or about 40 times the ignition energy required to ignite APG vapors. Thus, even the static electricity generated by a helicopter rotor is sufficient to ignite an APG vapor cloud. Therefore, if the aircraft were to fly into an APG vapor cloud between its upper and lower flammability limits, a flash fire or vapor cloud explosion (VCE) would occur, resulting in destruction of the aircraft and substantial damage or loss of the installation.

Mention is made of hydrogen sulfide (H_2S) which may be a constituent of “sour” APG. Sour gas is APG containing more than 5.7 mg-m^{-3} H2S, which is equivalent to 4 ppm by volume at standard temperature and pressure. H_2S is a highly toxic and flammable gas of great concern in hydrocarbon processing. It has wide flammability limits of between 4.3 to 46 percent by volume of air of which it is heavier. Because of its extreme toxicity, comparable to hydrogen cyanide, it is scrubbed from sour gas processes by use of highly efficient amine treating systems. For example, inhalation of a single breath of H_2S at or above 1,000 ppm results in immediate collapse and respiratory arrest from cellular hypoxia at the mitochondrial level; 1,000 ppm is 0.1 percent by volume. Thus, H_2S does not represent an engine ingestion hazard to helicopter operations in the way that C_1 through C_5 hydrocarbons do.

2.5 *Subtask C.4.5.2 (d) – (1) determine the concentration parameters for each flammable gas to determine the effect on helicopter operations*

Methodology

The concentration parameters for APG are combined with and discussed in Subtask C.4.5.2 (e), below.

Each of the helicopter engine manufacturers was contacted and asked if there was any specific operational limitation on the percentage of methane by volume. The FAA Type Certificate Data Sheet for each engine make and model was also consulted as well as operation and maintenance manuals.

Results

As discussed above in Subtask C.4.5.1 – Review and Assess Helideck Construction Standards, CAP 437 Section 2.3.5 states the maximum permissible concentration of hydrocarbon gas within the helicopter operating area is 10 percent of the lower flammable limit (LFL). Concentrations above 10 percent LFL have the potential to cause helicopter engines to surge and/or flameout with the consequent risk to the helicopter and its passengers. CAP 437 considered it unlikely that routine cold flaring would present any significant risk, but it was unclear on how that conclusion was reached. This 10 percent of LFL was based on CAA Paper 2008/03 and 99004 discussed above. The root paper, 99004, stated that this could not be determined without detailed study on the effects of hydrocarbon gas ingestion on turboshaft engines. This limitation is discussed further in Subtask C.4.5.2 (e) below.

The engine manufacturers contacted were Safran Turbomeca, Rolls-Royce/Allison, Pratt & Whitney, Lycoming Textron, and General Electric. Responses were received from Turbomeca, Rolls-Royce, and Lycoming. Turbomeca and Lycoming did not have an operating limitation for methane but it was unclear if this had actually been studied by the manufacturer. The FAA TCDS for the Turbomeca engines stated that the engines have not been tested to evaluate the effects of foreign object ingestion other than rain water. Rolls-Royce provided a copy of Customer Service Letter CSL-1230, dated 19 September 2001, which states:

Rolls-Royce has reviewed a recent inquiry regarding an acceptable level of methane gas for the operating environment of Model 250 engines. This information is considered valuable to all Model 250 operators who may operate in or near known atmospheric conditions which may contain levels of methane gas.

Rolls-Royce recommends a maximum methane/air mixture of 3% methane by volume. This level will minimize the risk of methane igniting inside the engine, outside of the combustion area. It is also recommended to avoid incursions with known methane gas by flying upwind and above the methane laden areas if possible.[19, 20]

2.6 *Subtask C.4.5.2 (d) – (2) specifically identify if each helicopter engine manufacturer has a known percentage of methane (or other combustible gas) to volume that is hazardous to engine operations.*

Methodology

The concentration parameters for APG are combined with and discussed in Subtask C.4.5.2 (e), below.

Each of the helicopter engine manufacturers were contacted and asked if there was any specific operational limitation on the percentage of methane by volume. The FAA Type Certificate Data Sheet (TCDS) for each engine make and model were also consulted as well as operation and maintenance manuals.

The FAA and NTSB were contacted and asked if there had been any research on APG ingestion. They provided no data or information regarding the question.[21]

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[19] Rolls-Royce Commercial Service Letter "Operations in Methane Laden Atmosphere", September 19, 2001

[20] Rolls-Royce was contacted and asked for engineering data to support the 3% methane limitation, but the OEM declined to provide any technical basis for the recommendation or participate in the methane ingestion study.

[21] Telephonic conversation with Jorge Fernandez, FAA Engine Certification Office (ANE-14), April 17, 2015

Results

As discussed above in Subtask C.4.5.1 – *Review and Assess Helideck Construction Standards*, CAP 437 Section 2.3.5 states the maximum permissible concentration of hydrocarbon gas within the helicopter operating area is 10 percent of the lower flammable limit (LFL). The LFL for methane is 4.4 percent by volume; thus 10 percent LFL for methane is 0.44 percent. Concentrations above 10 percent LFL have the potential to cause helicopter engines to surge and/or flameout with the consequent risk to the helicopter and its passengers. CAP 437 considered it unlikely that routine cold flaring would present any significant risk, but it was unclear on how that conclusion was reached. This 10 percent of LFL was based on CAA Paper 2008/03 and 99004 discussed above. The root paper, 99004, stated that this could not be determined without detailed study on the effects of hydrocarbon gas ingestion on turboshaft engines. This limitation is discussed further in Subtask C.4.5.2 (e) below.

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Rolls-Royce provided a copy of Commercial Service Letter “Operations in Methane Laden Atmosphere”, dated 19 September 2001, which states:

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>
> *Rolls-Royce recommends a maximum methane/air mixture of 3% methane by volume. This level will minimize the risk of methane igniting inside the engine, outside of the combustion area. It is also recommended to avoid incursions with known methane gas by flying upwind and above the methane laden areas if possible.*

There is a significant difference between 3.0% allowable methane environments the Rolls-Royce service bulletin, the only helicopter engine manufacturer to knowingly consider methane gas ingestion, and the 0.44% methane referenced by CAP 437 and which must be investigated; this is resolved by research discussed in Subtask C.4.5.2 (e) below.

The FAA provided a subject matter expert on rotorcraft engine foreign object ingestion who stated that there had been little, if any, actual research on this issue and that there were no engine certification requirements for APG ingestion.[23] The NTSB subject matter expert on helicopters

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[22] TCDS-Type Certificate Data Sheet: the technical data upon which the aircraft airworthiness approval is based.

[23] Telephonic conversation with Jorge Fernandez, FAA Engine Certification Office (ANE-14), April 17, 2015

stated that other than the two recent methane ingestion mishaps, the NTSB had not specifically investigated APG hazards to rotorcraft prior to issuing the safety notification to the Department of the Interior[24].

2.7 *Subtask C.4.5.2 (e) – evaluate the effect of the ingestion of each combustible gas on each helicopter (make, model, and engine), at anticipated concentration levels.*

Through evaluation of all publicly available engine test data, it was determined that no prior openly available testing was conducted in this area of engine performance research. As such, actual engine modelling was conducted at an appropriate facility under the sponsorship of this project that included three aircraft engines that were statistically valid representations of engines used for oil and gas aviation operations on the outer continental shelf. At a minimum, the research was designed to:

- Determine the theoretical effect of methane ingestion on the power output of the representative turboshaft engines;
- Assess the change of the engine operating point due to methane ingestion;
- Assess the likelihood of compressor stall and surge, or un-commanded power roll-back due to methane ingestion; and
- Assess any difference in performance degradation resistance between the hydromechanical fuel control and Full Authority Digital Engine Control (FADEC).

Background

To understand the complexity of this subtask, a brief review of turboshaft engine operation is appropriate.

The design features of gas turbine engines are varied. It is common to see engines in the same power classification and application which seem to have little or no resemblance to each other. To define the effects of methane ingestion on any individual engine design may or may not prove successful for the following reasons: [25]

> *Details of any particular engine design are proprietary trade secrets and may not be revealed or explained in technical literature by the original equipment manufacturer (OEM);*
>
> *Many engine designs are custom fit for a particular airframe for which it is intended to be installed and may not be a good fit for another airframe even if the airframe is in the same category and class – a compromise (design trade) is always necessary for operation over a wide variety of environmental conditions, fuels, weights, etc.;*

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[24] Appendix C-NTSB Safety Recommendations A-14-67 through -71

[25] Otis, C.E. (1997). Aircraft Gas Turbine Powerplants. Englewood, CO: Jeppesen-Sanderson, Inc.

> *Many engine designs depend on the prior experience of the OEM and regulatory approval hurdles may cage [force] the OEM into using a particular design that has been previously successful; and*
>
> *The OEM will often not explain in engineering technical terms the design parameters of the engine other than its predicted performance.*

Turboshaft Engine Construction and Operation Point

Turboshaft engines are Brayton Cycle gas turbine machines which deliver power through a shaft rather than operate a fan or propeller as in a turbofan or turboprop engine. Figure 10 presents a representation of the cross section of a Rolls-Royce Allison M250-C20J turboshaft engine which is widely used on helicopters.

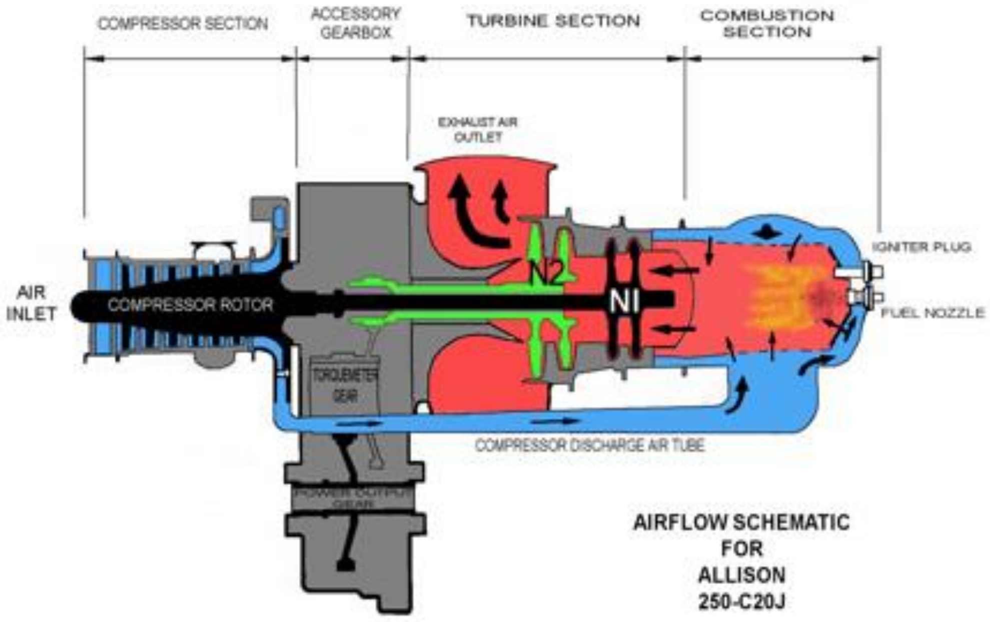

Figure 10: Airflow Schematic for Allison 250-C20J

The compressor section consists of a multistage axial and a single stage centrifugal compressor. The term axial flow applies to the axial (straight-line) flow of air through the compressor section of the engine. The axial-flow compressor has two main elements—a rotor and a stator. Each consecutive pair of rotor and stator blades makes a pressure stage. The rotor is a shaft with blades attached to it. These blades impel air rearward in the same manner as a propeller, by reason of their angle and airfoil contour. The rotor, turning at high speed, takes in air at the compressor inlet and impels it through a series of stages. The action of the rotor increases the compression of the air. At each stage it accelerates rearward. The stator blades act as diffusers, partially converting high velocity to pressure. Maintaining high efficiency requires small changes in the rate of diffusion at each stage. Conversely, the centrifugal-flow compressor consists of an impeller (rotor element), a diffuser (stator element), and a manifold. The impeller picks up and accelerates air outward to the diffuser. The diffuser directs air into the manifold. The manifold distributes air into the combustion section.

The combustion section provides the means for and houses the combustion process. Its function is to raise the temperature of the air passing through the engine. This process releases energy contained in the air and fuel by combustion. Igniters are installed in the combustion section to initially ignite the fuel-air mixture. As long as the fuel and air are provided to the combustor at the correct stoichiometric ratio and amount required for the power demand, the engine will continue to run without the use of the ignitors.

The combination of the compressor section, its driving N1 turbine, and the combustion section is often referred to as the gas generator. The gas generator's function is to produce the required energy to drive the power turbine (N2). The gas generator extracts about two-thirds of the combustion energy, leaving approximately one-third to drive the power turbine, which in turn drives the main and tail rotors through the power output shaft, as well as fuel control unit and other accessories through the power-takeoff pads on the accessory gearbox.

The location of the combustion section is directly between the compressor and the turbine sections. The combustion chambers are arranged coaxially with the compressor and turbines. The chambers must be in a through-flow position to function efficiently. About one-fourth of the air entering the combustion chamber area mixes with the fuel for combustion known as "primary air." The remaining air (secondary air) serves as temperature control which keeps the temperature of the heated gases down to a level at which the liners, turbine nozzles, or blades will not suffer thermal degradation and fail.

There is a real cycle or operation point for power output between the gas producer section and the power turbine section (see Figure 11below) known as the match point. A match point is simply a set of operating conditions (pressures, temperatures, and mass flows) were the compressor and turbine can work in unison and equilibrium. The operation point is based on compatibilities of flow, work, and rotational speed. This means:

- The compressor work must match the work output of the turbine that drives it (N1); and
- The mass flow rates must be compatible because gas turbines are continuous flow machines. Any disturbance in the mass flow rate will cause a mismatch between the compressor and turbine sections, decreasing or stopping the power output of the engine;

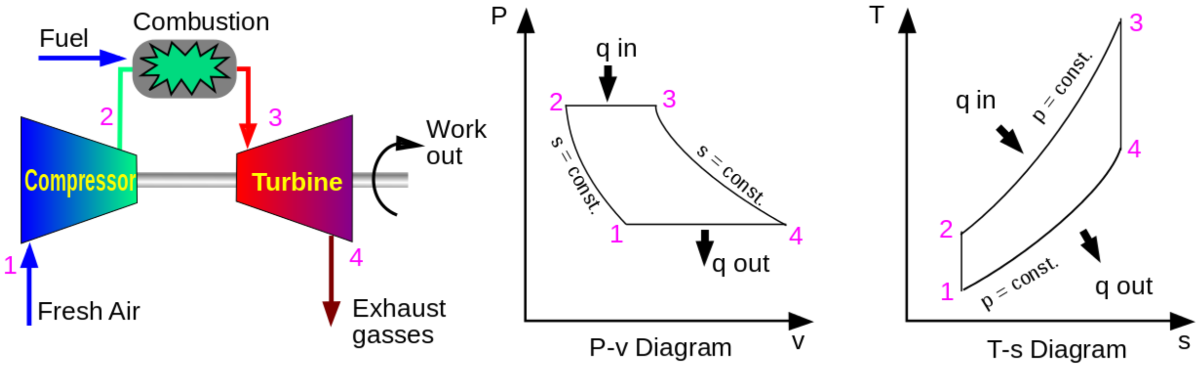

Figure 11: Gas Turbine Engine Brayton Cycle

A typical centrifugal compressor map is shown in Figure 12. Every compressor has a best operating point for a particular compression ratio, speed, and mass flow rate. The surge-stall line is the series of theoretical connecting points plotted on the compressor map. This line is verified by actual testing of the engine. The surge-stall line represents the maximum compression ratio and mass flow rate that the compressor is capable of maintaining at the operating speed. When these three parameters are proportionally matched, the engine will operate on normal operating line and produce the required power demanded by the aircraft. The normal operating line is below the surge-stall line and this distance is known as the stall margin. The stall margin allows for incremental changes to the inlet flow, temperature or compressor speed and the engine’s fuel schedule during acceleration and deceleration. If the compression ratio should change, the operating point will move up or down from the normal operating line out of synchronization with the compressor speed. Conversely, if the mass flow rate changes, the operating point will move to the right or left of the normal operating line out of symmetry with the compressor speed.

The normal operating line indicates that the engine will perform without surge or stall at the various compressor pressure ratios, speeds, and mass flow rates along the length of the line and below the surge-stall line. The design operating point is the point on the normal operating line at which the engine is expected to produce full power during most of its service life. From the compressor map, it may be seen that at any given compressor speed, a band of compressor pressure ratios and mass flow rates are acceptable for the engine to operate above the normal operating line. Moving the operating point above the surge line will cause the compressor to stall or surge. The operating point may be moved by altering the fuel-air mixture or inlet air temperature; either may have an adverse effect on the power output of the engine.

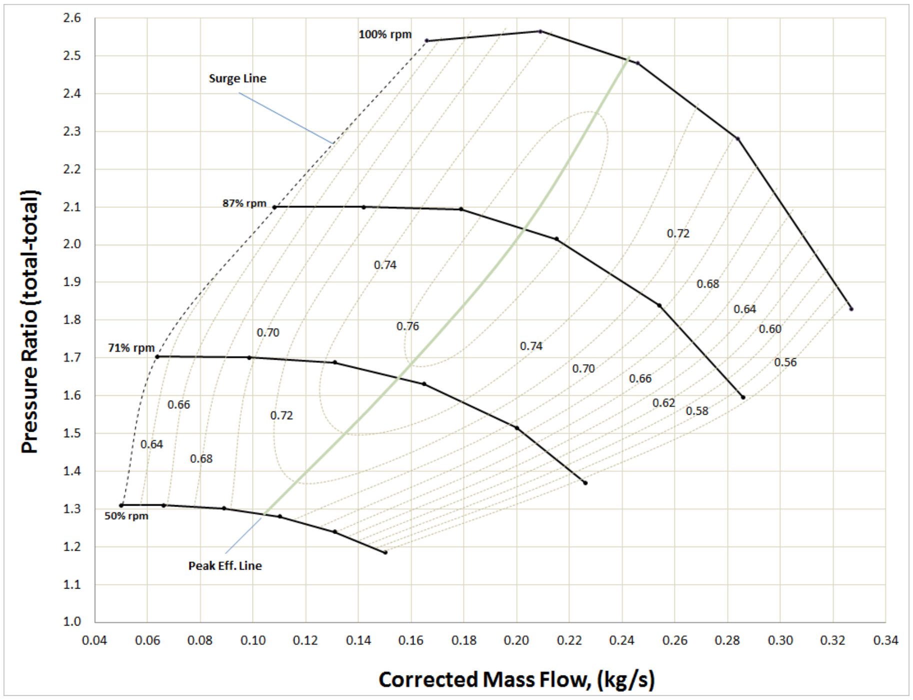

Figure 12: Example of Gas Turbine Engine Compressor Map

Compressor maps of actual engines are OEM proprietary trade secrets, judiciously guarded by the manufacturer and not released to PwC/BSEE for this study.

Compressor Stall and Surge

The blades of an axial compressor or the vanes of a centrifugal compressor are airfoils in that they have a critical angle of attack; exceeding the angle of attack will cause the compressor to stall. The apparent angle of attack of the compressor is related to the inlet air velocity and compressor speed. The two forces combine to form a vector, which is the actual angle of attack of the air approaching the airfoil. A compressor stall is an imbalance between these two vector quantities and cause air flowing through the compressor to slow down, stagnate (stop), or to reverse direction (surge), depending upon the stall intensity. Stall conditions usually produce an audible sound from a pulsating sound to a loud explosion or backfire, depending upon the severity of the stall. Often, engine instrumentation does not indicate a mild stall condition known as a transient stall. Severe stalls, known as "hung stalls," or surge, significantly decay engine performance with attendant un-commanded power rollback, internal damage, or complete engine failure.[26] Compressor stalls and surges may result from many causes, but most common are:

- Turbulent or disrupted airflow to the engine inlet which reduces the velocity vector (common to high speed aircraft only);

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[26] Otis, C.E. (1997). Aircraft Gas Turbine Powerplants. Englewood, CO: Jeppesen-Sanderson, Inc.

- Excessive fuel flow caused by abrupt engine acceleration which reduces the velocity vector by increasing combustor back pressure;
- Excessively lean fuel mixture caused by abrupt engine deceleration which increases the velocity vector by reducing combustor back pressure;
- Contaminated or damaged compressors which increases the velocity vector by reducing compression efficiency;
- Damaged turbine components causing loss of power to the compressor and low compression which increases the velocity vector by reducing compression efficiency; or
- Engine operation above or below the design operating point which increases or decreases the compressor speed vector.

When the engine is operating at its design operation point, the compressor blades are at a high angle of attack which is often very close to the stall line but which gives the maximum efficient pressure rise per stage of compression. There is also a maximum combustor back pressure and restriction to flow created by the turbine system that can be tolerated by the engine. Thus, for the engine to operate correctly and produce the power demanded by the aircraft for flight, the compressor pressure ratio and mass flow rate must remain within a balanced relationship (the operating point) as discussed above. This can only occur if the operating conditions (inlet compression ratio, compressor efficiency, fuel flow, turbine efficiency, and exhaust nozzle flow) all remain within the designed operating parameters. If they do not, a compressor stall or surge may develop with partial or complete loss of engine power.

Flameout

A flameout occurs in the operation of a gas turbine engine in which the combustion in the engine is unintentionally extinguished. If the upper flammability limit of the fuel-air stoichiometric ratio is exceeded in the combustion chamber, the self-propagating flame will be extinguished by the air flow through the engine. This condition is often referred to as a rich flameout and generally results from very fast engine acceleration, in which an overly rich mixture causes the fuel temperature to drop below the combustion temperature. It may also be caused by insufficient airflow to support combustion.

A more common flameout occurrence is due to low fuel pressure and low engine speeds, which typically are associated with high-altitude flight or reduced power settings. This situation usually occurs with the engine throttled back during a descent, which can lead to the air-fuel stoichiometric ratio being below the lower flammability limit (LFL), often referred to as the lean-condition flameout. A stoichiometric mixture close to the LFL can easily cause the flame to die out, even with a normal airflow through the engine.

Any interruption of the fuel supply can result in a flameout. This may be due to prolonged unusual attitudes, a malfunctioning fuel control system, turbulence, icing, or fuel contamination, starvation or exhaustion.

Gas Turbine Fuel Control

Fuel control for gas turbine engines may be by conventional hydro-mechanical fuel control (HMFC), sometimes called a hydro-pneumatic fuel control system; electronic fuel control by use of an electronic control unit (ECU); or through a full-authority digital engine control (FADEC). While gas turbine engine fuel control is complex, a brief synopsis of each system is presented.

Hydromechanical Fuel Control (HMFC)

This fuel control system (Figure 13) is a hydro-mechanical metering device that consists of an engine-drive fuel pump, a fuel control unit (FCU), a fuel metering section, power turbine governor, and a fuel distribution manifold and injection nozzles. The HMFC is designed to perform the following functions:

- Change fuel flow with changes in air density as sensed at the engine inlet;
- Schedule fuel flow during starting to prevent hot or hang starts;
- Schedule fuel flow during engine acceleration to prevent compressor stall or surge and excessive turbine gas temperature (TGT);
- Schedule fuel flow for ground and flight idle conditions to prevent flameout;
- Schedule fuel flow for flight based on compressor inlet air temperature and pressure, compressor and power turbine speeds, and collective position;
- Provide an overspeed governor for ground and flight operation;
- Provide manual selection of main rotor speed through collective trimming system;
- Allow for selection of power output (torque and TGT) in the flight range by movement of the collective control coordinator to be automatically maintained regardless of altitude, free-air temperature, or forward airspeed; and
- Allow manual or electric cutoff of fuel for engine stop.

The fuel pump is typically a positive displacement gyrator-type pump driven from a PTO[27] pad on the accessory gearbox and delivers high pressure fuel to the FCU. The FCU is also driven from a PTO pad on the accessory gearbox at a speed proportion to the compressor turbine speed (N1). The FCU determines the fuel schedule of the engine to provide the required power output and for controlling the speed of the compressor turbine. Engine power output is directly dependent upon compressor turbine speed. Control of the compressor turbine is accomplished by regulating the amount of fuel supplied to the combustion section of the engine through the distribution manifold and injection nozzles.

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[27] PTO-power takeoff: a device that transfers mechanical power from an engine to another piece of equipment:

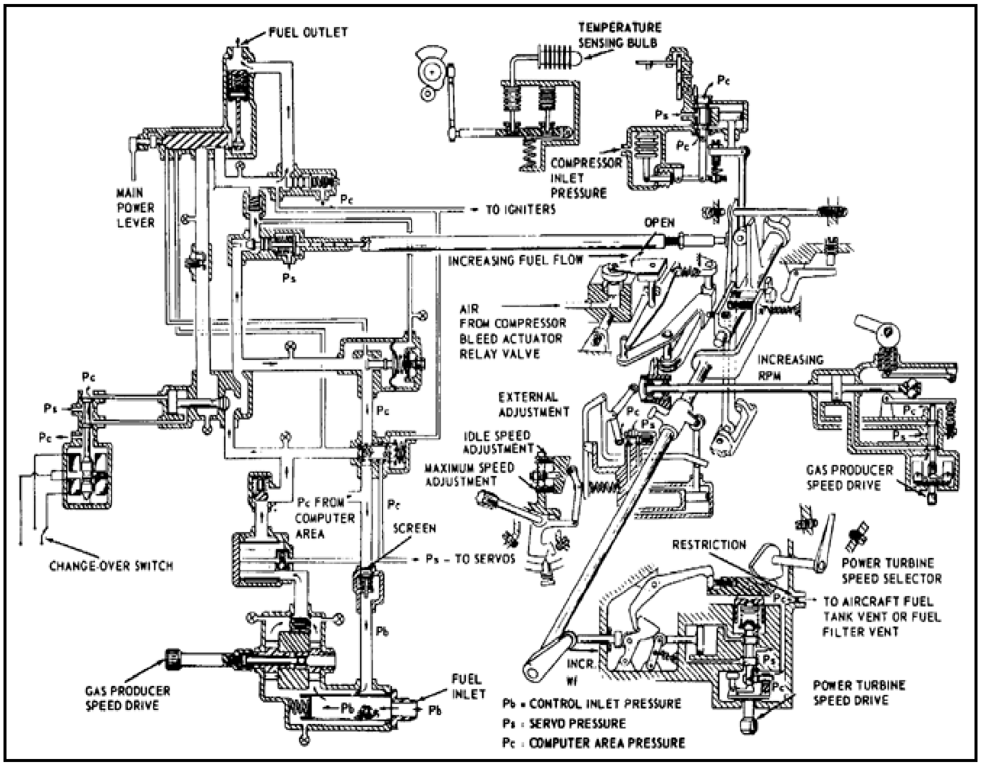

Figure 13: Hydromechanical Fuel Control System for Rolls-Royce Allison 250 Turboshaft Engine

The FCU contains a fuel metering section. The FCU is supplied with fuel from the engine-driven fuel pump at pump pressure. Fuel flow to the combustion section is governed by a main metering valve. The pneumatic fuel computing section senses compressor inlet pressure (Pc) through a pneumatic line connected to the compressor discharge scroll. As discussed above, the FCU controls engine power output by controlling the gas producer speed. Gas producer speed levels are established by the action of the power turbine fuel governor which senses power turbine speed (N2). The power turbine (load) speed is selected by the operator through the control of the collective and power required to maintain this speed is automatically maintained by power turbine governor action on metered fuel flow. The power turbine governor lever schedules the power turbine governor requirements. The power turbine governor schedules the gas producer speed to a changed power output to maintain output shaft speed.

Electronic Fuel Control Unit (ECU or EFCU)

Electronic fuel control is basically a hydromechanical fuel control with an electronic trimming system which gives the engine better acceleration response and enhanced compressor stall protection. The addition of the electronic trimming system provides the following functions:

- Provides positive over-temperature protection during starting and acceleration;

- Allows the engine to operate closer to the maximum turbine gas temperature (TGT) due to more accurate monitoring of fuel schedule;
- Permits selection of any desired TGT to be automatically maintained without manually trimming the engine;
- Allows use of a wide variety of fuels with different lower heat values (LHV) such as kerosene (JP4) without recalibration of the HMFC fuel control;
- Permits the use of bleed air for anti-icing without changing power settings while avoiding over-temperature conditions;
- Trims fuel schedule to compensate for erroneous compressor inlet sensing by FCU caused by different aircraft installations;
- Provides more uniform collective settings for torque output; and
- Provides a “lock in” function for fuel correction prior to landing for more balanced engine power.

The system uses a number of electronic sensors for compressor speed (N1), power turbine speed (N2), compressor pressure (Pc), collective control angle, and turbine gas temperature (TGT). The sensors provide analog electric signals, typically 4-20 mA, to the electronic engine control (EEC). The EEC then computes the fuel required fuel schedule based on the programed operating parameters and power demand and actuates a proportional fuel control solenoid on the hydromechanical fuel control unit to maintain the desired power output. In the event of a failure of the EEC, the hydromechanical fuel control can act as a backup fuel control and the EEC can be manually overridden by the operator.

Full-Authority Digital Engine Control (FADEC)

Many modern helicopters are equipped with a full-authority digital engine control (FADEC). The FADEC consists of a digital computer, referred to as the electronic engine controller (EEC), engine control unit (ECU), or the electronic engine control unit (EECU), and its related accessories that control all aspects of aircraft engine performance. A true FADEC has no form of manual override available, placing full authority over the operating parameters of the engine in the decision algorithms of the EECU.

The EECU is a programmable logic controller (PLC) which has proportional-integral-derivative (PID) control. The PID controller calculates an error value as the difference between measured engine parameters and their desired operating points. The PID controller minimizes the error by adjusting the engine power through use of a manipulated variable in fuel scheduling. For optimum control of the engine, the PID is overlaid with a digital Kalman filter. The Kalman filter uses a linear quadratic estimation algorithm that uses a series of engine parameter measurements observed over time which contain statistical noise and other inaccuracies and produces estimates of unknown variables that tend to be more precise than those based on the engine parameter measurements alone. The PID-Kalman filter optimum FADEC provides robust control of engine operation and protects against starting anomalies, compressor stall and surge, and over-torque, over-temperature, or flameout conditions without pilot monitoring or intervention.

The FADEC controls the power output of the engine by controlling power turbine output independently of the power demand of the engine by very fine adjustments of the gas producer. The EECU provides fuel flow modulation through output signals to a stepper motor driving a fuel metering valve on the hydromechanical fuel control unit. The EECU receives multiple input variables of the current flight condition including air density, collective control position, compressor and turbine temperatures and pressures, and bleed valve position over a digital data bus. These parameters are analyzed multiple times per second and corrections to the gas generator through fuel scheduling are applied, giving precise, fault-tolerant optimum control over engine power output for any given flight condition.

The FADEC system is the most critical part of the engine and rotor speed control, and may be powered by the aircraft's main electrical system. In many aircraft, the FADEC uses power from a separate generator connected to the engine and operates as soon as the gas generator speed is sufficient (>60% of maximum capacity). In either case, there must be a backup electrical source available because failure of a FADEC system could result in a complete loss of engine power. To prevent loss of power, two separate and identical digital channels are incorporated for redundancy, each channel capable of providing all engine and rotor speed control functions without limitations. Moreover, some aircraft are equipped with dual FADEC to provide redundancy. Dual redundant FADEC systems increase reliability in that no single point failure of the engine control system can result in a complete loss of engine power.

Helicopter Takeoff and Landing Procedures

The probability of the aircraft encountering an APG vapor cloud is dependent upon local environmental conditions such as the magnitude and direction of the wind, relative position of the helideck to the APG source, and the flight path of the aircraft on takeoff and landing. Helicopter takeoff and landing procedures are dictated by the aircraft flight manual (AFM). The procedures in the AFM, in turn, are predicated on FAR Part 27 or 29 under which the aircraft is certificated. Normal category helicopters are certificated under FAR Part 27 which specifies a MGTOW of 7,000 lb. or less. However, multiengine normal category helicopters may be certificated under FAR Part 29 if the aircraft meets the Category A[28] takeoff and landing performance criteria. Conversely, transport category helicopters are certificated under FAR Part 29 and must be certificated as either Category A or Category B[29]. The differences in Category A and Category B certification depend upon the passenger capacity and MGTOW.

For takeoff and landing, there is little difference between normal single-engine and transport Category B procedures. Normal single-engine helicopters, naturally, do not have any ability to maintain flight in the event of an engine failure and must autorotate to a safe landing. Transport Category B helicopters do not have guaranteed performance margin to maintain flight in certain

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[28] 14 CFR §29.53 defines a Category A takeoff as one in which the helicopter, should an engine fail at any time after the start of takeoff, is able to (a) return to, and stop safely on, the takeoff area; or (b) continue the takeoff, climbout, and attain a configuration and airspeed allowing compliance with §29.67(a)(2).

[29] 14 CFR §29.63 defines a Category B takeoff as one where the helicopter must be able to climb over a 50-foot obstacle in a defined distance, under most unfavorable center of gravity condition, and land safely at any point along the flight path if an engine fails.

one-engine inoperative (OEI) flight regimes that Category A helicopters do. Figure 14 is a diagram of a normal or Category B takeoff and emergency flight paths.

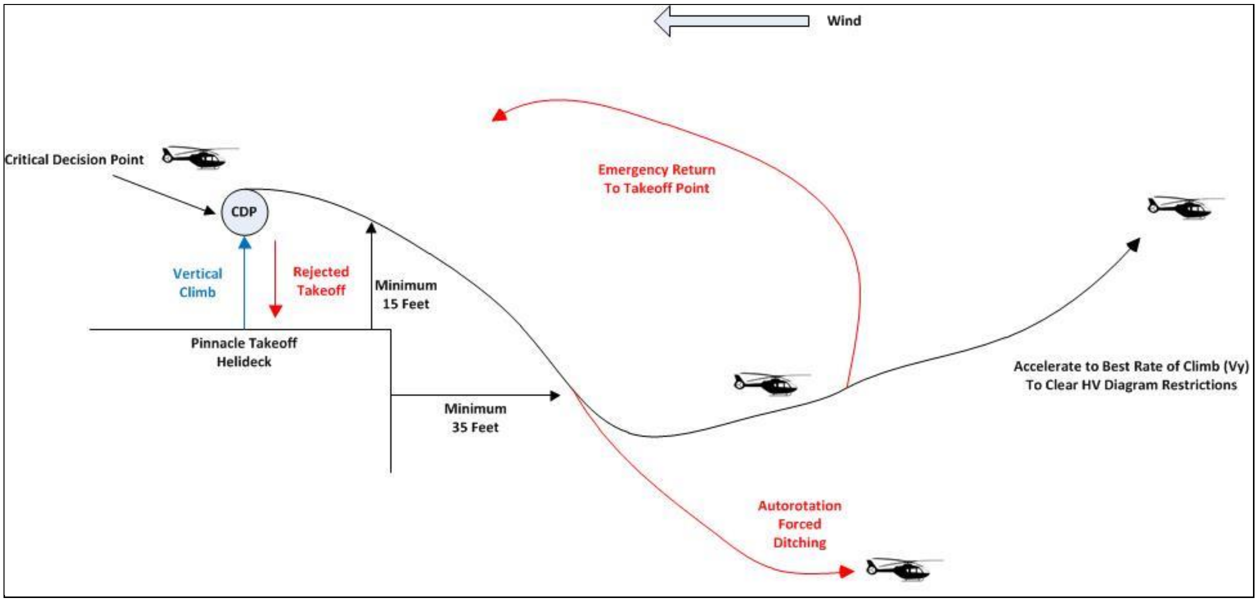

Figure 14: Normal and Category B Takeoff and Emergency Flight Paths

In a normal single-engine or Category B takeoff, the helicopter first performs an in ground effect hovering (HIGE) power check then ascends to the takeoff decision point (TDP[30]); sometimes, the HIGE check and CDP may be the same altitude but is generally not less than one-half rotor diameter or approximately 15 feet above the surface. The helicopter is then accelerated through effective translational lift (ETL) and then to best rate of climb airspeed (or best angle of climb airspeed for physical obstacles) to clear operational restrictions imposed by the height-velocity (HV[31]) diagram in the AFM[32]. In the event of an engine anomaly, the aircraft will either set back down or will make an emergency return to the helideck; in the event there is insufficient engine power for flight after departure, the aircraft will autorotate to a forced ditching.

FAR Part 29 Category A certificated helicopters, however, are multiengine aircraft designed with engine and system isolation features that ensure that if one engine fails after takeoff or during landing, the aircraft can safely land on the helideck or climb out from the point of failure and attain a stabilized OEI[33] flight path. When operating OEI, the inoperative engine must be able to be isolated. Additionally, there are flight instrument requirements such as a radar altimeter to allow the pilot to conduct a Category A takeoff. Figure 15 is a diagram of Category A takeoff and OEI procedures.

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[30] TDP-Takeoff decision point (TDP): Category A: the first point from which a continued takeoff capability is assured under 14 CFR§29.59 and is the last point in the takeoff path from which a rejected takeoff is assured within the distance determined under 14 CFR§29.62. (see 14 CFR§29.55)

[31] HV diagram-Height-velocity envelope -a helicopter specific graph showing the combination of height and forward velocity (including hover) under which a safe landing cannot be made after failure of the critical engine. (see 14 CFR§29.87)

[32] AFM-Aircraft Flight Manual

[33] OEI-one engine inoperative

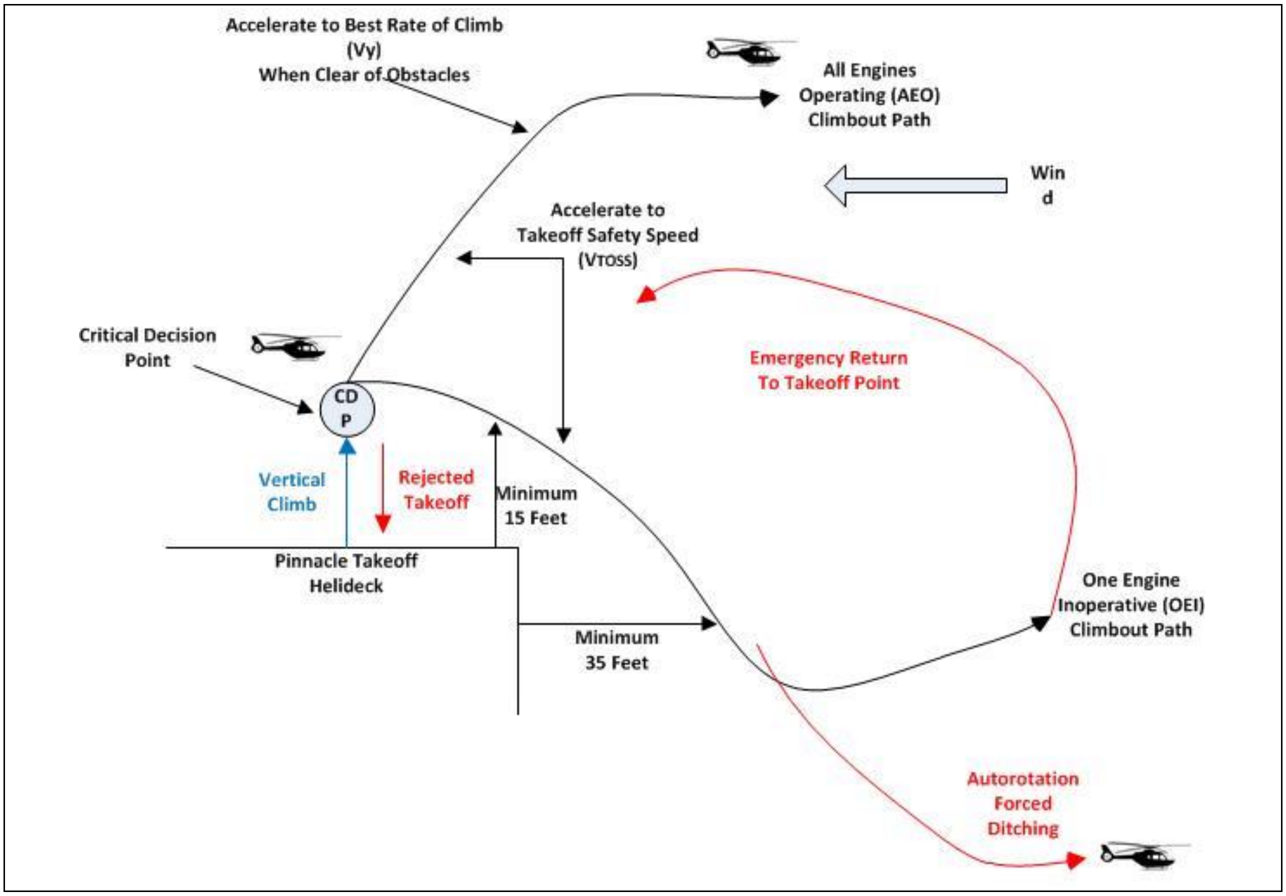

Figure 15: Category A Takeoff and Emergency Flight Paths

In a Category A takeoff, the helicopter will perform the HIGE power check then ascend to the (TDP). The TDP is often 100 feet or more and the vertical ascent ensures that the helicopter can land OEI on the helideck in the event of an engine failure. Once the aircraft reaches the CDP and is operating with all engines (AEO), the helicopter is accelerated to the takeoff safety speed (V_{TOSS}). Operation at the V_{TOSS} ensures that the aircraft is at a sufficient energy state to climb OEI and maintain flight. In the event of an engine failure at the CDP, the pilot may elect to vertically set the aircraft back on the helideck or fly away OEI and make an emergency return. In the unlikely event of a double engine failure or transmission warning, the pilot may elect to autorotate to a forced ditching.

Landing on a helideck may be considered a pinnacle, confined space, or steep approach landing, depending upon the AFM. Figure 16 shows the conventional approach and landing to a helideck.

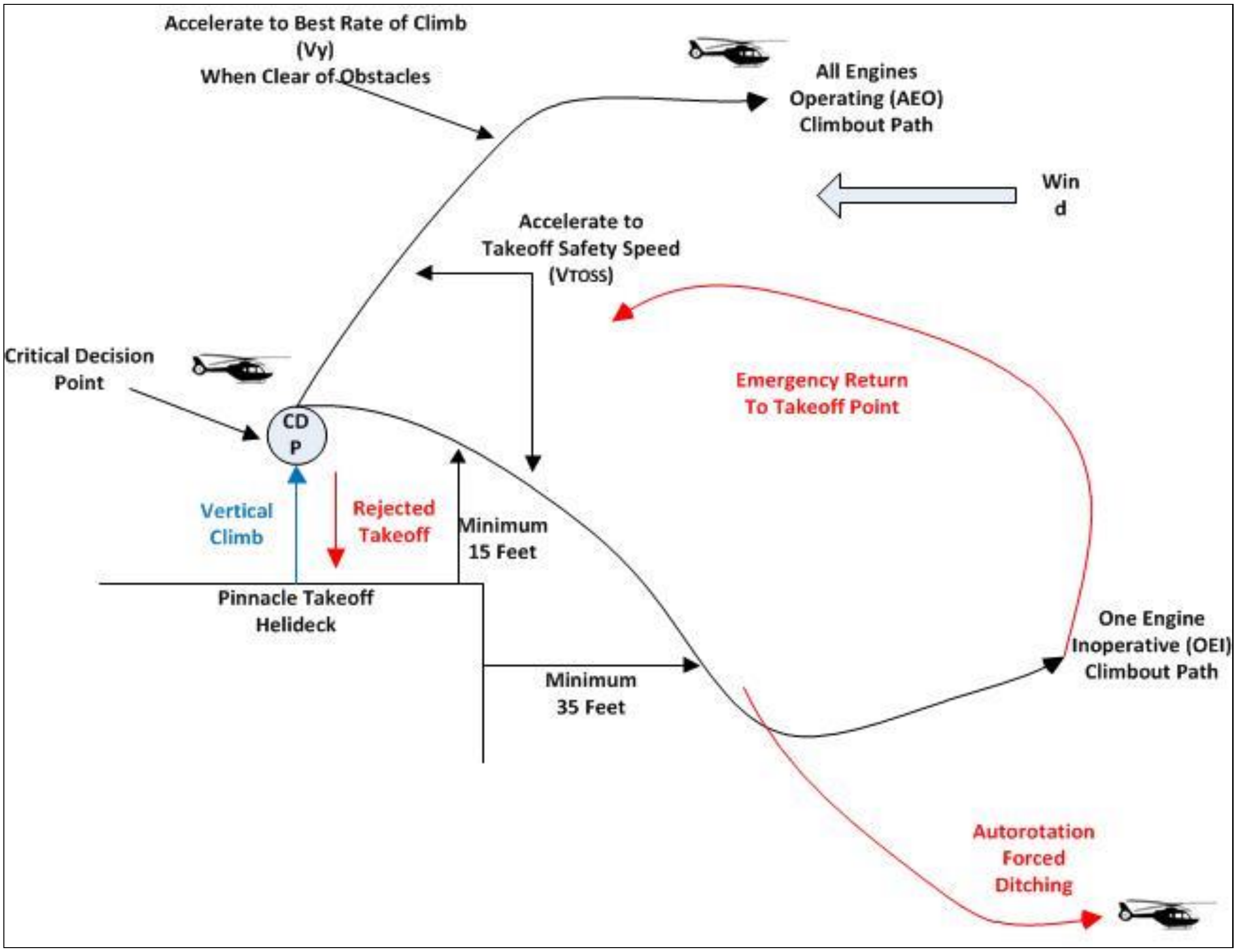

Figure 16: Conventional Approach and Landing Flight Path

The helicopter will normally conduct both a high and low reconnaissance of the helideck to ascertain hazards. Once the pilot is sure that it is safe to land, an approach into the wind is made to the landing decision point (LDP). If engine operations are normal or an engine fails after reaching the LDP, the pilot will normally elect to continue the landing to the helideck as the safest course of action. However, if the engine operations are abnormal or an engine fails before the LDP, the pilot may elect to fly off OEI and return to a shore heliport or runway.

Understanding of Category A and B takeoff, landing, and emergency procedures discussed above is necessary to understand the hazards presented by APG during these operations. Since methane is lighter than air and most stacks and many flare booms are above the helideck, it is unlikely that methane would accumulate on the helideck and present a hazard to the aircraft while on the deck. However, Category A takeoff procedures or Category B climb out may present a methane ingestion hazard to the aircraft if the wind is within the critical sectors discussed earlier and depicted in Figure 4.

Effects of Methane Ingestion on Turboshaft Power Output

Methodology

This task requires a technical analysis to determine the concentration for each flammable gas which may have an effect on helicopter performance, and to evaluate the effect of hydrocarbon gas ingestion of each combustible gas on each helicopter (make, model, and engine) at the anticipated concentration. As discussed above, more than 90 percent of APG gas released from offshore installations is methane so only methane need be considered to produce a valid result. Concerning the make, model, and engine of helicopters used on the OCS, there is no current test data available in order to conduct an analysis for each make, model, and engine configuration. However, according to the Helicopter Safety Advisory Conference (HSAC) data, single-engine turbine helicopters make up the bulk of the OCS helicopter fleet. These helicopters are powered by more than 30 different engine model numbers. All of these engine models, however, share common gas producer characteristics and fall into one of three categories:

- Joined multistage-axial and single-stage centrifugal compressor;
- Single-stage centrifugal compressor; or
- Split multistage-axial and single-stage centrifugal compressor.

Thus, an effective analysis was completed by analyzing the effects of methane ingestion on the three types of compressor configurations. Therefore, three representative turboshaft engines widely used in helicopter power applications are selected to perform this engineering analysis:

- Engine A has a joined multistage axial and single-stage centrifugal compressor section, a two-stage low-pressure gas generator turbine (N1), and two-stage high-pressure power turbine (N2) section;
- Engine B has a single-stage centrifugal compressor section, a two-stage low-pressure gas generator turbine (N1), and two-stage high-pressure power turbine (N2) section; and
- Engine C has a split single-stage axial and single-stage centrifugal compressor section, a single-stage gas generator turbine (N1), and a single-stage power turbine (N2) section.

These engines are chosen to represent a statistically valid sample of the helicopter turboshaft engine population operating on the OCS.

Figure 17 presents a cause and effect diagram of possible events due to APG ingestion in a turboshaft engine. The dependent variables are ingestion of APG, compressor surge, and actual crash of the aircraft; conversely, the independent variables are the APG stoichiometric concentration in air, and the compressor configuration of the representative engine. For example, a helicopter may or may not encounter an invisible APG vapor cloud, depending upon wind direction. If the helicopter encounters an APG vapor cloud, the stoichiometric concentration may cause a compressor surge. The effect of the compressor surge, perforce, depends on its severity and the time that the fuel control or the pilot has to respond to the event to prevent a mishap.

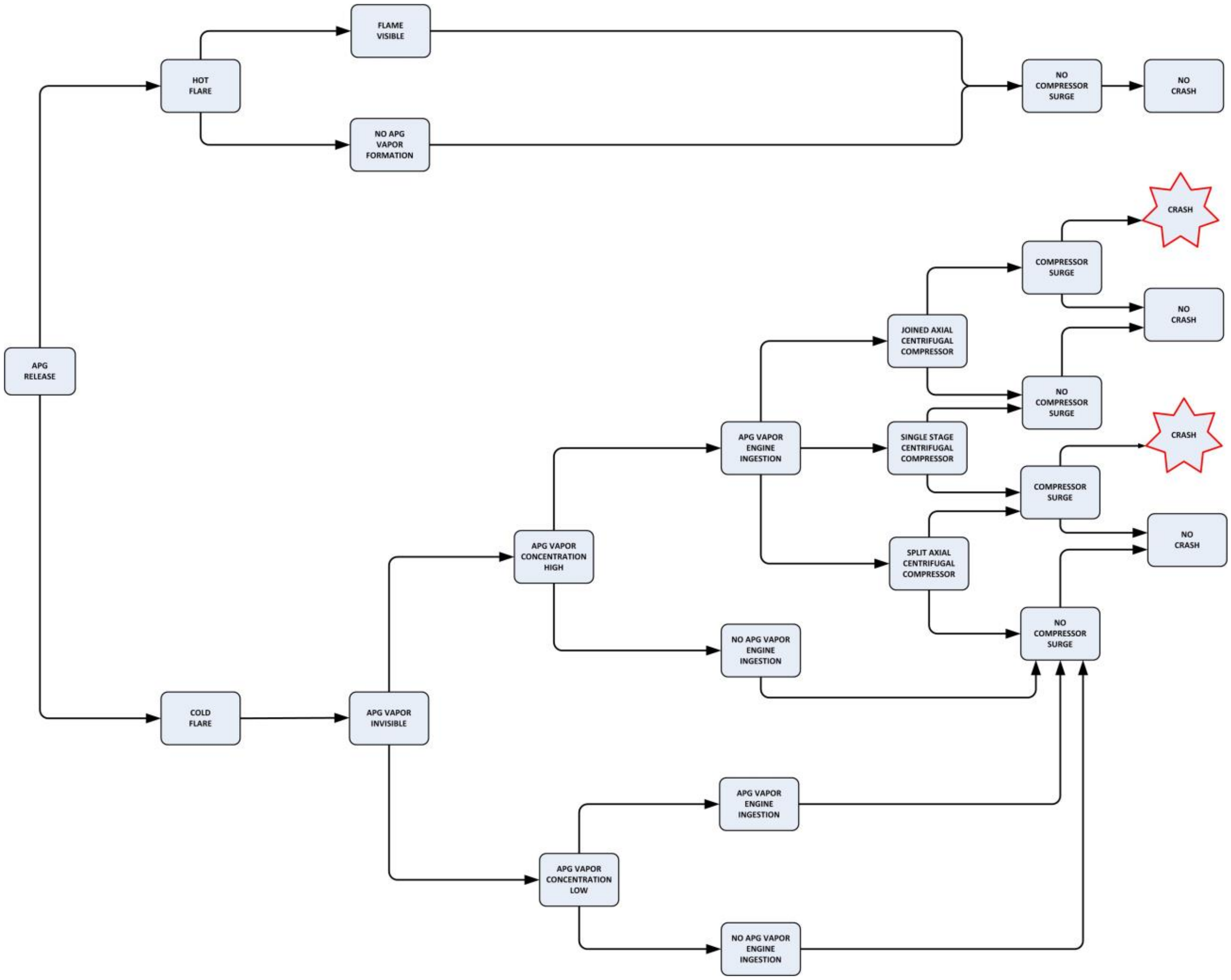

Figure 17: APG Ingestion Event Tree

Due to the thermodynamic operating characteristics of gas turbine turboshaft engines, methane gas ingested into the engine could either be ignited through adiabatic compression heating above the autoignition temperature causing a compressor surge, or enrich the fuel causing an over-temperature condition with associated internal engine pressure increase, increase in compressor backpressure, or over-speed condition, all of which may cause a partial or total loss of engine power.

The engineering modeling of methane ingestion effects on turboshaft engine operating point and real cycle power output was performed by the gas turbine engine laboratory (PropLab) at the Aerospace Engineering Department of Texas A&M University in College Station, Texas. The preliminary engineering analysis report is provided as Appendix F as a separate document.

The engine response to methane ingestion was mathematically modelled using the required engine parameters to describe the real cycle power output at maximum takeoff power. These include the overall pressure ratio (OPR), mass airflow rate ($\dot{m}_{air}$) and power (hp). Additional parameters, including inlet diffuser efficiency, compressor efficiency, turbine inlet temperature

(T3), pressure drop in combustor section (Δp), combustor efficiency, mechanical losses, turbine efficiency, power turbine efficiency, differential pressure at nozzle expansion, and nozzle efficiency, are assumed to obtain a brake specific fuel consumption (BSFC) in µg/J at takeoff conditions when the pressure is one bar and the static temperature is 288.16°K. Engine operating parameters were derived from published engine operation and maintenance manuals, performance charts, and proprietary data provided by the engine OEM. Standard Jet A fuel is assumed in the real cycle computation such that the lower heating value (LHV) is 43,500 kJ-kg^{-1} (with the exception of Engine C which was 43,136 kJ-kg^{-1}) and the stoichiometric ratio between mass flow rates and air and fuel was 14.66.

The real cycle for the three turboshaft engines was calculated using a numerical summation for enthalpy (kJ-kg^{-1}), temperature (°K), entropy (kJ-(kg-°K)$^{-1}$), and pressure (bar). These values are used to describe the theoretical effect of methane ingestion on the compressor (adiabatic compression ignition) and fuel enrichment on the combustor on the real cycle and thus power output of each representative engine. Fractions of methane ingestion are 0, 5, 10, and 15 percent by volume with all concentrations reported by mass.

The effect on the combustor and power output as a function of the turbine inlet temperature (TIT) as an expression of engine power output and was calculated from the energy conservation equation. The conservation of energy between the compressor and combustor is calculated as follows:

$$\begin{aligned}\dot{m}_{a1}h_a(T_2^*) + \dot{m}_{CH_4}\left(h_{CH_4}(T_2^*) + \xi_{CH_4}LHV_{Ch4}\right) + \dot{m}_f\left(h_f + \xi_{comb}LHV\right) \\ = \dot{m}_{a_{left}}h_a(T_3^*) + \dot{m}_{\lambda=1}h_{\lambda=1} + \dot{m}_{proCH_4}h_{proCH_4}(T_3^*)\end{aligned}$$

where:

- $\dot{m}_{a1}$ is the mass flow rate of air after methane injection;
- h_a is the enthalpy of air;
- $\dot{m}_{CH_4}$ is the mass flow rate of methane;
- ξ_{CH_4} is the efficiency of methane combustion;
- LHV_{Ch4} is the lower heating value (LHV) of methane;
- $\dot{m}_f$ is the mass flow rate of fuel (Jet A) prior to methane ingestion;
- h_f is the enthalpy of fuel;
- ξ_{comb} is the efficiency of Jet A combustion;
- LHV is the lower heating value of Jet A fuel;
- $\dot{m}_{a_{left}}$ is the mass flow rate of air that did not burn in the combustor;
- $\dot{m}_{\lambda=1}$ is the mass flow rate of combustion products resulting from the stoichiometric combustion of Jet A fuel;

- $h_{\lambda=1}$ is the enthalpy of combustion products resulting from the stoichiometric combustion of Jet A fuel;
- $\dot{m}_{proCH_4}$ is the mass flow rate of combustion products resulting from the stoichiometric combustion of methane;
- h_{proCH_4} is the enthalpy of combustion products resulted from the stoichiometric combustion of methane; and
- T_3^* is the turbine inlet temperature (TIT) in °K at stagnation.

Response to the changes in the turboshaft engine real cycle by various fuel control systems is qualitatively described.

Assumptions and Limitations

The methane ingestion in the compressor section is assumed to be uniform. Non-uniformity conditions are ignored but may cause local stall cells to form which are not predicted by this modelling.

Methane ingestion at the engine intake is assumed to be at the specified concentrations. The actual probability of these methane concentrations is dependent upon non-linear factors such as release rate, distance to source, wind magnitude and direction, and mechanical mixing of clean air into vapor cloud by the main rotor and are ignored.

Effects of local fluid strain rate and effect on auto-ignition and flame propagation is also ignored. If fluid strain rate is considered, this would lower the probability of an autoignition.

Any ram pressure recovery at the compressor is ignored as this effect does not occur until 100 m/s forward airspeed (194 KTAS[34]).

Results

Effect on Compressor Section

Data calculated by the mathematical modelling show that methane ingestion slightly reduces temperature at the exit of the compressor. In all representative turboshaft engines, the temperature at the exit of the compressor is below the minimum autoignition temperature of 810°K[35]. Therefore**, it is unlikely within a reasonable degree of engineering and scientific certainty that the methane will ignite in the compressor due to adiabatic heating.**

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[34] KTAS-knots true airspeed; velocity in nautical miles per hour corrected for temperature and pressure altitude

[35] Robinson, C. and Smith, D.B. (1986). The auto-ignition temperature of methane. *Journal of Hazardous Materials 8*, 199-203.

Effect on Combustor Section

This section presents the effect of methane ignition in the combustor on the turbine inlet temperature (T_3, TIT). The TIT was calculated from the energy conservation equation discussed in the methodology. It was assumed that the mass flow rate of fuel (Jet A) did not change immediately after methane ingestion, that is, the fuel control unit scheduler did not have sufficient time to adjust to the lower amount of combustion air. Therefore, the temperature reached immediately after methane ingestion is the top limit for the engine, since subsequently the fuel scheduler should reduce the mass flow rate of fuel (Jet A) once the methane ignites in the combustor.

The TIT variation as a function of the mass flow rate of methane ingested was assumed that 90% of the lower heating value of methane, which is 50,050 kJ-kg^{-1}, was transferred to the working fluid. It was also assumed that the lower heating value of Jet A is 43,136 kJ-kg^{-1}, which is identical to the value used for Engine C, but different from the value previously used for Engines A and B (see Figure 1 in Appendix F).

The methane volume fraction range (1% to 18%) corresponds to a mass fraction range of 0.55% to 10.83%.

Discussion

The results provided in Appendix F revealed that, for the three representative engines examined, the temperature in the compressor is not high enough to ignite the methane-air mixture. Even if the temperature would exceed the minimum auto-ignition temperature, the flow strain would require an even higher temperature for auto-ignition.

The methane will certainly ignite in the combustor. Consequently, the turbine inlet temperature (TIT) will sharply increase. For a methane volume fraction ranging between 1% and 18%, the temperature will increase be approximately 120K[36] to 1,100 K. Depending on the temperature rise, the pressure of in the combustor section will rise with two effects. First, the back pressure on the compressor will rapidly increase, upsetting the operating point and moving it beyond the surge line on the compressor map, more likely than not resulting in a compressor stall and surge. Second, the increase in combustor pressure will increase the N1 and N2 turbine speeds not commanded by the fuel control system. The fuel control system will sense this as an overspeed condition and decrease the fuel schedule, even to the flight idle underspeed governor limit, causing an un-commanded power rollback as the methane fuel enrichment is rapidly exhausted. Recovery of the engine output power depends on the type of fuel control unit (HMFC, ECU, or FADEC) and the control inputs of the operator. Because the effects of the methane ingestion are rapid, there may likely be insufficient reaction time for the pilot to diagnose the condition and would have no option but to suffer the effects of an engine power loss.

Even small amounts (mass fractions) of methane, as low as 0.4% by volume, may cause a power loss in the representative engines.

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[36] K (Kelvin)- the primary unit of temperature measurement in fluid dynamics; one of the seven base units in the International System of Units (SI); e.g. absolute zero (0 K) is equivalent to −273.15 °C (−459.67 °F)

Hydromechanical fuel control units (HMFC), while robust and not as complex as electronic control units, are probably not as resistant to transient conditions such as a compressor stall or TIT spikes caused by a methane ingestion event. Electronic fuel trimming systems, while more efficient than HMFC, are likely no more resistant to the type of transient conditions caused by methane ingestion. FADEC systems that incorporate a signal to noise control filtering system such as a Kalman filter, however, are more likely than not to be resistant to engine power perturbations caused by small methane ingestion events (<0.4%).

Note: The actual performance of the fuel control units cannot be modeled or determined without empirical testing on a turboshaft engine so equipped.

2.8 *Subtask C.4.5.3 – monitoring and warning systems*

General Description

This subtask requires the identification and evaluation of (1) technologies to monitor combustible gases that could adversely affect helicopter operations in the vicinity of an OCS facility (on the helideck and during approach and departure); (2) the determination if/how a sensor for vented gas can be devised/installed around the helidecks and oil rigs to advise pilots of the quality of the environment they intend to fly through on takeoff and landing; and (3), to investigate mitigation strategies such as installing diffusers or other systems on vent stacks that would reduce the risk of methane or combustible gases.

Monitoring Technologies

Methodology

A detailed review of available hydrocarbon gas detection systems and detector specifications was made, including industry best practices.

Results

There are several, mature hydrocarbon gas detection technologies used in offshore, petrochemical, and other hydrocarbon hazard facilities; these are catalytic gas detection, infrared gas detection, and hydrocarbon gas imaging.

Catalytic Gas Detection

A catalytic gas detector works by the electrical heating of a wire and a rare earth catalyst as the sensing element. The element responds to an influx of combustible hydrocarbon gas by increasing its temperature and resistance of the sensing element. This change in resistance is proportional to the volume fraction of the hydrocarbon gas in air. The change in resistance is converted to an analog voltage signal which can then be displayed on an indicator or used to activate an alarm system.

Poisoning of this type of detector can be caused by substances such as silicon-based greases, and, in some cases, excessively high background gas concentrations outside the upper explosive limit.

Other problems associated with catalytic detectors include the blockage of the sintered disc with particles such as oils, fine dust, salt, grit, corrosion or even water.

Catalytic detectors are point-source type detectors and must be located in very close proximity to potential points of gas release to be effective. Moreover, the calibration of the detector must account for differences in gas densities, and therefore, must be mounted at an elevated level to ensure detection of a methane gas release. As such, the catalytic detectors are not considered best practice for methane detection and are not used in facilities with the potential for large methane releases such as LNG plants or vessels.

Infrared Gas Detectors

Advances in infrared (IR) technology have produced both point and open-path detector systems. IR gas detectors operate by the physical principle that APG absorbs infrared energy at certain wavelengths.

The point IR gas detector is a sealed detection tube containing both IR transmitter and receiver. The output is proportional to the amount of IR absorbed by the gas and thus the gas present in the vicinity of the detector.

Conversely, the open-path IR gas detector is synonymous with a conventional optical beam smoke detector in appearance and configuration. It works by measuring the attenuation of IR by a vapor cloud between the transmitter and receiver over a large area (line of sight). The optical beam measures the total amount of gas present in the sensor path as if a row of point-type detectors had been placed end to end in a line; this allows the significance of the gas release hazard to be estimated.

Open-path detectors are effective over a long distance with typical coverages up to 300 meters (985 feet). Practical effective detection limits are less than 100 meters (328 feet) to ensure accuracy and reduce nuisance alarms. This operational feature makes these types of detector ideal for perimeter monitoring. However, like all optically-based detector systems, they are very susceptible to contamination, rain or fog.

Hydrocarbon Gas Imaging

One technology which may be viable for warning pilots of potential APG hazards it a hydrocarbon gas imaging system. These systems are quite new and similar to forward-looking infrared (FLIR) technology. Using this imaging technology, it is possible to actually ‘see’ a vapor gas cloud in real time. It is also possible to compare the gas cloud to the condensate cloud surrounding the gas cloud. In a test at Texas A&M University on an extremely humid day, the condensate cloud was three to four times the size of the methane cloud, but also acted as an insulator in stagnant wind conditions which would have rendered IR detectors useless.[37]

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[37] Most APG could be visually detected at ground level or at one or two meters height. Gas imaging may be carried out up to 50 meters (164 feet) from the target area. This technology may be explored to see if it could be adapted to helideck monitoring.

Warning Systems

A helicopter pilot needs real-time information concerning the wind direction and speed, temperature, and air quality in the immediate area of the helideck, in order to make a well-informed decision on whether to initiate an approach to landing or to takeoff. The questions that must be asked are:

- What is the quality of the air in the immediate vicinity of the landing surface?
- What is the quality of the air on the approach path?
- What is the quality of the air on the departure path?

To capture sufficient quality and quantity of information concerning the properties of the air in the vicinity of the helideck, multiple sensors would need to be installed. A sensor designed to report the air quality of the helideck and approach and departure paths would need to be located in a position to allow real-time sampling of those critical areas. The mounting structure and sensor would need to be positioned so that they did not create in flight hazards that were disproportionate to their intended utility.

On first approximation, it appears that open-path IR type gas detectors would be ideal for monitoring helidecks for APG contamination. However, there are severe limitation that renders the system non-effective for warning the helicopter pilot of an APG hazard.

It would be possible to mount both point and open-path gas detectors in the plume path from the flare to the helideck and on the helideck itself, but the flight path above the helideck could not be covered. Therefore, depending upon wind magnitude and direction, as well as the volume of the APG release, all approach and departure paths for the aircraft could not be effectively monitored. This is especially true for Category A takeoff for twin-engine transport helicopters which require a vertical ascent as discussed above.

Locating point detectors on the aircraft itself would not be feasible as the detector would not activate until the aircraft had entered the vapor cloud, thus not providing the pilot with enough reaction time to avoid the hazard.

Typically, the alarm setpoint is 20% of LFL to ensure adequate detection as they are less reliable at lower setpoints, and to reduce nuisance alarms. As discussed above, 10% LFL is the maximum recommended exposure for turboshaft engines. Thus, setting the detector at 10% LFL may degrade the detection capability of the system at the recommended maximum gas exposure level and generate nuisance alarms, degrading personnel confidence in the efficacy of the system.

Mitigation Strategies

Methodology

A detailed review of design of flare systems was made, including industry best practices. Consultation with process safety and design subject matter experts was also conducted.

Results

As discussed above, APG is normally separated from liquid hydrocarbons. If economically viable, the gas is separated into its constituent components, compressed and piped to shore for additional processing, distribution and sale. If the amount of APG is not sufficient to be economically viable for separation and sale, it is hot flared or cold vented to the atmosphere.

Numerous gas flow meters exist and are currently in use to determine the amount of APG released into the atmosphere and routinely used on offshore facilities to satisfy EPA greenhouse gas reporting requirements.

There is no technological means of eliminating APG from base hydrocarbon production. It is technologically possible to entrain air into the flare outlet such that the percentage of APG is below the 10% LFL at discharge, using pressure and flow regulating valves in the flare header, coupled with venturi mixers at the flare stack. However, this system would have to be designed and retrofitted to all legacy facilities at substantial cost. Moreover, the system would have to be designed such that the volumetric concentration could be varied between the desired 10% of LFL to within the flammability limits such that the gas could be hot flared when desired or required. There are some flows which the intermittent volume of APG would render this system impracticable due to complexity. Lastly, increasing complexity into the flare system may produce other hazards such as leak points or additional on-facility hydrocarbon inventory which may result in a greater fire and explosion hazard than the facility was originally designed to withstand.

In lieu of flaring or venting APG, the constituent gases may be separated and concentrated on board the facility until sufficient quantities exist for economically offloading, processing, distribution, and sale.

For example, two ways of storing methane gas are by compression to generate compressed natural gas (CNG) or cryogenic liquefaction to produce liquefied natural gas (LNG); other constituents of APG such as butane and propane could be separated and compressed to generate liquefied petroleum gas (LPG). Once the inventory of CNG, LNG or LPG reaches an economically viable level, it can be offloaded from the facility to a transfer vessel and taken to shore for processing, distribution and sale. This may only be economically effective for large producing wells.

However, for legacy facilities, more likely than not, there is insufficient space to install the required compressors, storage vessels, and associated piping to make it economically feasible. Moreover, concentration of APG constituents presents fire, explosion, and blast effects hazards for which the facility was not originally designed. This is one of the root causes of the Piper Alpha disaster – failure to consider the increased hydrocarbon inventory when converting from gas to both gas and liquid hydrocarbon processing. For example, the blast walls on the processing facility or the separation distance between the processing and accommodation platforms may be insufficient if the APG processing capability is added.

3. ***Recommendations***

This section provides recommendations to minimize or eliminate the release of methane or other combustible gases within an area determined to pose a risk to helicopter operations to BSEE upon completion of all activities under Task 5 as required by Subtask C.4.5.4, Recommendation Report.

3.1 ***Subtask C.4.5.1 – review and assess helideck construction standards***

Review of domestic and international regulations and standards reveals that the recommendations provided in API 14J and the draft version of API 2L-1 are sufficiently comprehensive to ensure that hazards presented by APG are considered and mitigated.

Engineering studies should be commissioned to predict the theoretical concentration of APG that may be present in an APG vapor cloud based on computational fluid dynamics (CFD) gas dispersion modelling. These studies should consider the effect the mechanical mixing of clean air from the main rotor during approach or departure.

These studies should define several representative platform configurations prevalent in US OCS operations; and examine multiple natural wind scenarios, including “light and variable”, “steady-state” and “gusty” conditions. The effects of approaching and departing helicopters of various weight categories should also be incorporated into the modelling. This study may identify platform configurations that are problematic for helicopter operations with respect to hot exhaust plumes and APG venting.

Increased temperatures due to hot exhaust plumes are as great or greater risk than APG ingestion due to significant increased risk of gas turbine compressor stall. The CFD analyses recommended above should include temperature distributions and the position of the 2°C isotherm should be verified as specified in NORSOK C004.

BSEE should work with HSAC to improve the HSAC RP No. 92-4 to develop enhanced operational and communication procedures to mitigate the hazards presented by APG as discussed below.

3.2 ***Subtask C.4.5.2 (a) – identify and list each regulation that addresses venting and flaring of methane on OCS facilities under BSEE jurisdiction, highlighting any regulation that favors one method over the other.***

APG flaring and venting on the OCS, with the exception of EPA reporting requirements, is essentially unregulated. Under 42 U.S.C. 7401, et seq. or 30 C.F.R. §250.1900, et seq., it does not appear that BSEE has any authority to regulate APG venting or flaring under SEMS or the Clean Air Act.

3.3 ***Subtask C.4.5.2 (d) – (1) determine the concentration parameters for each flammable gas to determine the effect on helicopter operations; and (2) specifically identify if each helicopter engine manufacturer has a known***

percentage of methane (or other combustible gas) to volume that is hazardous to engine operations.

No publicly available research on the hazard of APG ingestion has been conducted by the turboshaft engine OEMs, or by regulatory agencies in the U.S. In the investigation of APG ingestion mishaps, the NTSB has relied on USAF AFWAL-TR-80-2090, *Water Ingestion into Axial Flow Compressors, Part III, Experimental Results and Discussion*, which tangentially mentions methane ingestion effects when the gas was used to simulate rainwater ingestion. This report was issued in 1981 and considerable changes in technology with respect to empirical engine testing and instrumentation has occurred in the last three decades. The FAA Rotorcraft Directorate (ASW-100) and the FAA Rotorcraft Certification Office (ASW-170), both located at Meacham Field in Fort Worth, Texas, should be invited to participate in an engineering empirical test on the APG ingestion hazard. Since the independent variable is the fuel control unit, this study should include empirical testing on one representative engine equipped with a hydromechanical fuel control and one with a FADEC system to verify the mathematical modelling and resistance to engine performance anomalies. The OEM should also be encouraged to participate and provide technical assistance.

3.4 *Subtask C.4.5.2 (e) – evaluate the effect of the ingestion of each combustible gas on each helicopter (make, model, and engine), at anticipated concentration levels.*

Mathematically modelling the effects of methane ingestion on turboshaft engines suggests that less than one-half of one percent by volume of methane may have an adverse effect on engine power resulting in a mishap. From the NTSB data reviewed, it appears that an APG ingestion mishap may have occurred every 1.5 years on the OCS; near miss data for when an APG ingestion event occurred but did not result in the loss of the aircraft is not reported or collected. Therefore, rotorcraft operators should be encouraged to submit incidents through its SafeOCS or a similar incident reporting system. These incidents should be thoroughly investigated through a root cause analysis (RCA) methodology and the data trended over time to quantify the magnitude of the hazard.

Until the effect of APG ingestion is verified by empirical experiment, universal precautionary operational procedures to mitigate the APG hazard should be promulgated. This could be accomplished either by regulatory changes or through industry best practices such as modification of HSAC RP 92-4.

Until a CFD gas dispersion model is constructed for each offshore oil & gas facility in accordance with the recommendation in Subtask C.4.5.1 above, helidecks should universally be considered contaminated with APG whenever the wind direction is within 10 degrees of the platform’s designated flaring/venting critical wind zone and the facility is cold venting APG. Critical approach and departure wind zones, as depicted in Figure 18, below should be established for each facility. If the facility does not have a Helicopter Traffic Coordination Center (HTCC), a meteorological monitoring or helideck monitoring system (HMS), in accordance with NORSOK C004, should be installed in the communication center for the facility. Positive radio contact with the facility must be made prior to landing or departure.

The facility must communicate meteorological and safety advisory information to the incoming aircraft in addition to declaring the helideck clear to land or depart. This information should include wind speed and direction, temperature, dew point, barometric pressure, and cautionary advisories for APG cold venting, a general caution to remain clear of the flare boom or stack and hot exhaust systems, and an advisory on any known helicopter traffic similar to a UNICOM request for aerodrome information.

The no fly zone azimuths should be provided on a facility diagram to aid in the safety communications.

Facility offshore installation managers (OIM) and personnel who communicate with incoming and departing aircraft should be trained on the procedures. These procedures are especially applicable to Category A takeoffs where the vertical ascent requirements for OEI safety may increase the probability of encountering an APG vapor cloud. Helicopters approaching or taking off from a facility without a positive communications exchange are operating at increased risk.

Gas flow monitoring devices should be installed in the APG distribution system to report the instantaneous volume of APG venting if the helideck is to be operational during APG release. As recommended in Subtask C.4.5.3 (a) above and based on a CFD gas dispersion study, point and open-path gas detectors should be installed on the helideck perimeter and in the path from the APG source to the helideck. Installation of a helideck visual warning indication system as discussed in API RP 2L-1, 5th Edition, should be considered.

It should be noted that hot flaring of APG does not provide a greater level of protection to the aircraft. While it does eliminate the APG and make the flare plume more visible to the pilot, as discussed in NORSOK C004, hot gas emissions are a serious risk to turboshaft engines, perhaps even more significant than methane ingestion. Momentary temperature increases of 2°C or more may result in an engine power loss event. Unless the position of the 2°C isotherm line, with respect to the helideck position at the least favorable wind conditions, is verified by CFD analysis, hot flaring of the APG may not provide any more protection than venting APG; therefore, continuous hot flaring is not recommended as a safety measure.

Lastly, while FADEC controlled engines may have more resistance to transient conditions, at least one mishap directly attributable to APG ingestion occurred to an aircraft equipped with a FADEC. Therefore, universal precautions concerning the APG hazard are recommended when operating in the immediate vicinity of a facility that may be venting APG and a restriction to FADEC equipped aircraft only is not recommended without empirical engine testing.

3.5 *Subtask C.4.5.3 (a) – monitoring technologies*

Installation of a combination of point and open-path IR gas detectors in and around the helideck may be feasible if the setpoint of the detector could be calibrated to 10% LFL of methane or lower without degrading the detection capability of the system or generation of nuisance alarms. An engineering study to determine the efficacy of this technology should be commissioned.

An engineering study should be commissioned to determine if hydrocarbon gas imaging technology is supplemental or superior to IR gas detection for providing advance warning to helicopter flight crews of APG hazards.

3.6 *Subtask C.4.5.3 (b) – mitigation strategies*

A risk analysis of alternatives (RiskAoA) study should be commissioned to determine the feasibility of either equipping new build facilities or retrofitting legacy facilities with vent flow regulation and additional air entrainment systems to lower the vent stack emissions below the 10% LFL limit. This study should include a CFD analysis and a hazardous operation (HAZOP) analysis to determine both safety and efficacy of the system on a test facility.

If the RiskAoA study finds that installation of these flare regulating systems is feasible, operators should be encouraged to evaluate incorporation of a flare regulating system on each facility.

An equally useful and cost effective engineering safety control would be a system that warned of cold venting in-progress. This reporting mechanism should be highly visible in all light and weather conditions and should also broadcast venting and wind information over the platform frequency used for pilot-to-platform communications.

Figure 18 depicts an imaginary flare/vent boom and helideck configuration. The footprint of the platform and proximity of the flare/vent tip will determine a triangular-shaped region of wind directions within which approaches and departures would be ill-advised, when flaring or venting was in progress. The platform would have to be manned with a person capable of reading available wind information and transmitting it in real-time to an approaching or departing helicopter.

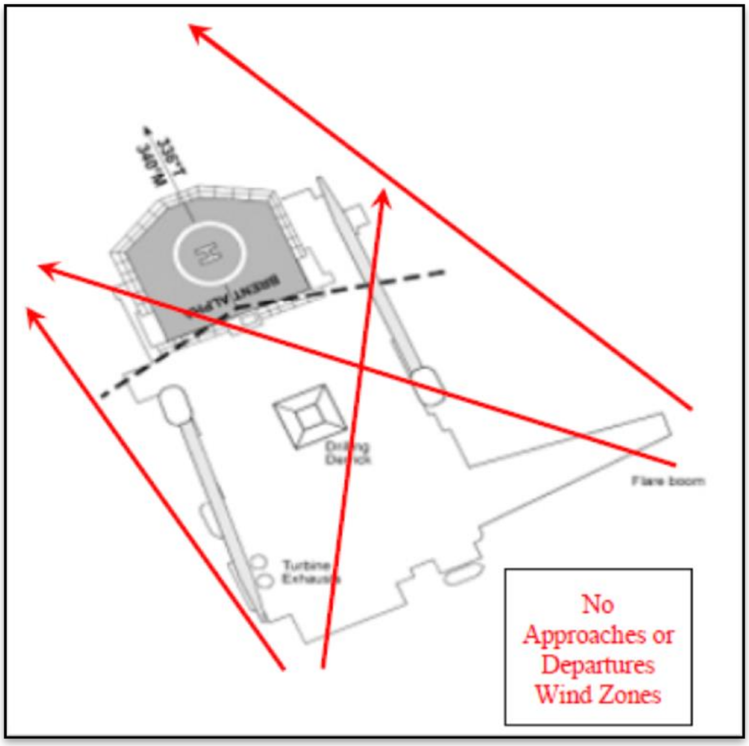

Figure 18: No Approaches or Departures Wind Zone Depiction

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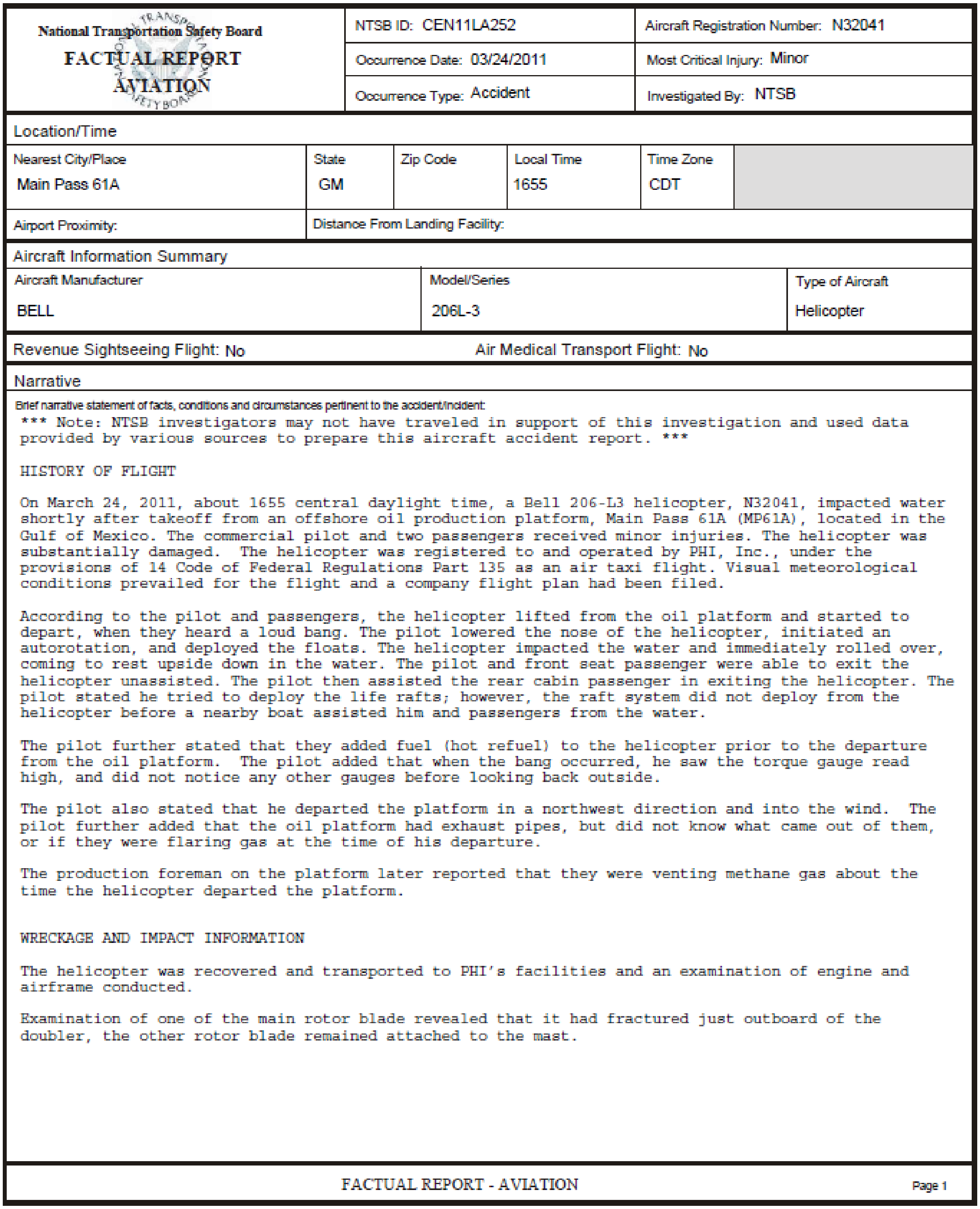
5. *Appendix A-NTSB CEN11LA252*



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN11LA252	Aircraft Registration Number: N32041
Occurrence Date: 03/24/2011	Most Critical Injury: Minor
Occurrence Type: Accident	Investigated By: NTSB

Location/Time

Nearest City/Place	State	Zip Code	Local Time	Time Zone
Main Pass 61A	GM		1655	CDT

Airport Proximity: Distance From Landing Facility:

Aircraft Information Summary

Aircraft Manufacturer	Model/Series	Type of Aircraft
BELL	206L-3	Helicopter

Revenue Sightseeing Flight: No Air Medical Transport Flight: No

Narrative

Brief narrative statement of facts, conditions and circumstances pertinent to the accident/incident:

*** Note: NTSB investigators may not have traveled in support of this investigation and used data provided by various sources to prepare this aircraft accident report. ***

HISTORY OF FLIGHT

On March 24, 2011, about 1655 central daylight time, a Bell 206-L3 helicopter, N32041, impacted water shortly after takeoff from an offshore oil production platform, Main Pass 61A (MP61A), located in the Gulf of Mexico. The commercial pilot and two passengers received minor injuries. The helicopter was substantially damaged. The helicopter was registered to and operated by PHI, Inc., under the provisions of 14 Code of Federal Regulations Part 135 as an air taxi flight. Visual meteorological conditions prevailed for the flight and a company flight plan had been filed.

According to the pilot and passengers, the helicopter lifted from the oil platform and started to depart, when they heard a loud bang. The pilot lowered the nose of the helicopter, initiated an autorotation, and deployed the floats. The helicopter impacted the water and immediately rolled over, coming to rest upside down in the water. The pilot and front seat passenger were able to exit the helicopter unassisted. The pilot then assisted the rear cabin passenger in exiting the helicopter. The pilot stated he tried to deploy the life rafts; however, the raft system did not deploy from the helicopter before a nearby boat assisted him and passengers from the water.

The pilot further stated that they added fuel (hot refuel) to the helicopter prior to the departure from the oil platform. The pilot added that when the bang occurred, he saw the torque gauge read high, and did not notice any other gauges before looking back outside.

The pilot also stated that he departed the platform in a northwest direction and into the wind. The pilot further added that the oil platform had exhaust pipes, but did not know what came out of them, or if they were flaring gas at the time of his departure.

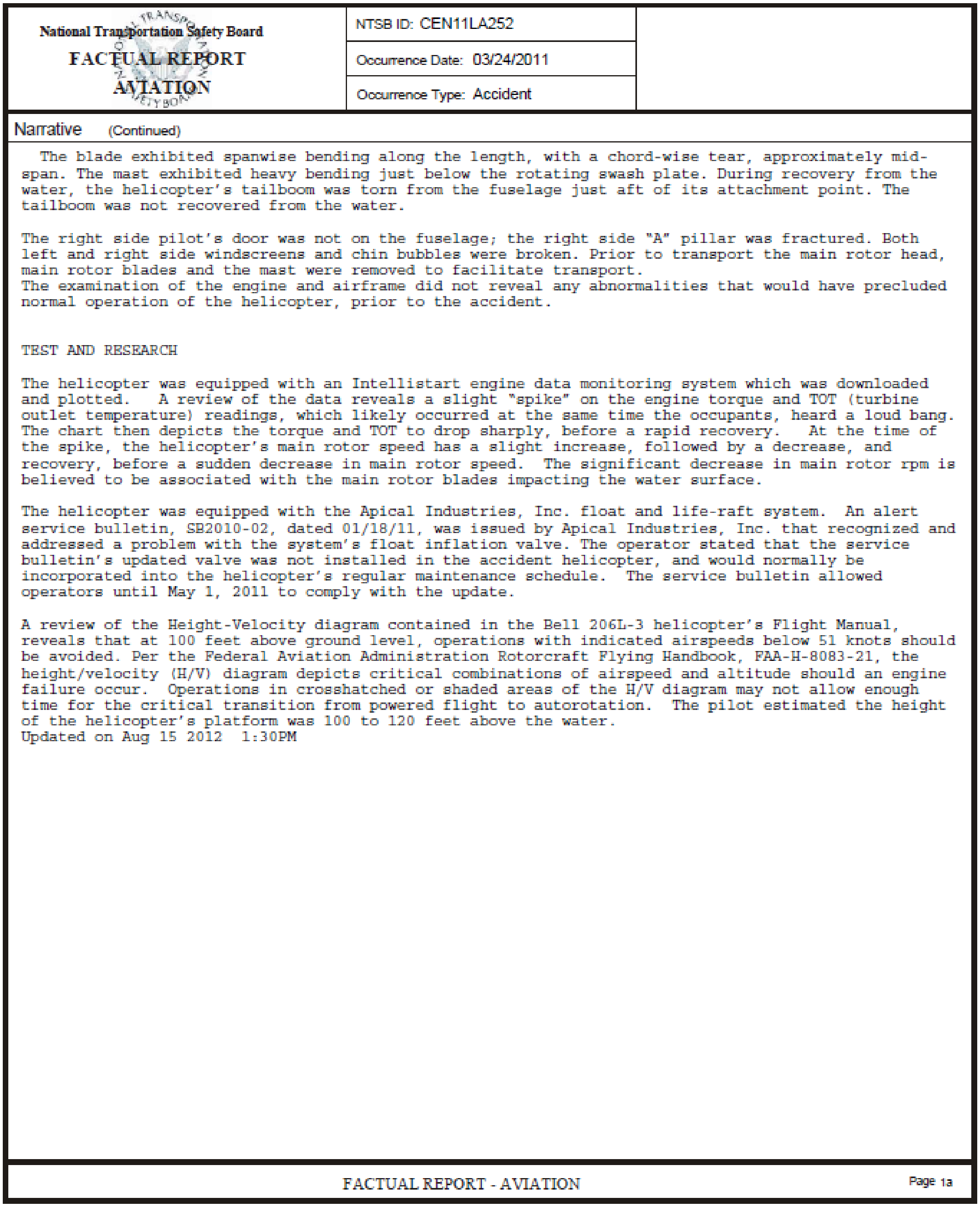
The production foreman on the platform later reported that they were venting methane gas about the time the helicopter departed the platform.

WRECKAGE AND IMPACT INFORMATION

The helicopter was recovered and transported to PHI's facilities and an examination of engine and airframe conducted.

Examination of one of the main rotor blade revealed that it had fractured just outboard of the doubler, the other rotor blade remained attached to the mast.

FACTUAL REPORT - AVIATION Page 1



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN11LA252

Occurrence Date: 03/24/2011

Occurrence Type: Accident

Narrative (Continued)

The blade exhibited spanwise bending along the length, with a chord-wise tear, approximately mid-span. The mast exhibited heavy bending just below the rotating swash plate. During recovery from the water, the helicopter's tailboom was torn from the fuselage just aft of its attachment point. The tailboom was not recovered from the water.

The right side pilot's door was not on the fuselage; the right side "A" pillar was fractured. Both left and right side windscreens and chin bubbles were broken. Prior to transport the main rotor head, main rotor blades and the mast were removed to facilitate transport.
The examination of the engine and airframe did not reveal any abnormalities that would have precluded normal operation of the helicopter, prior to the accident.

TEST AND RESEARCH

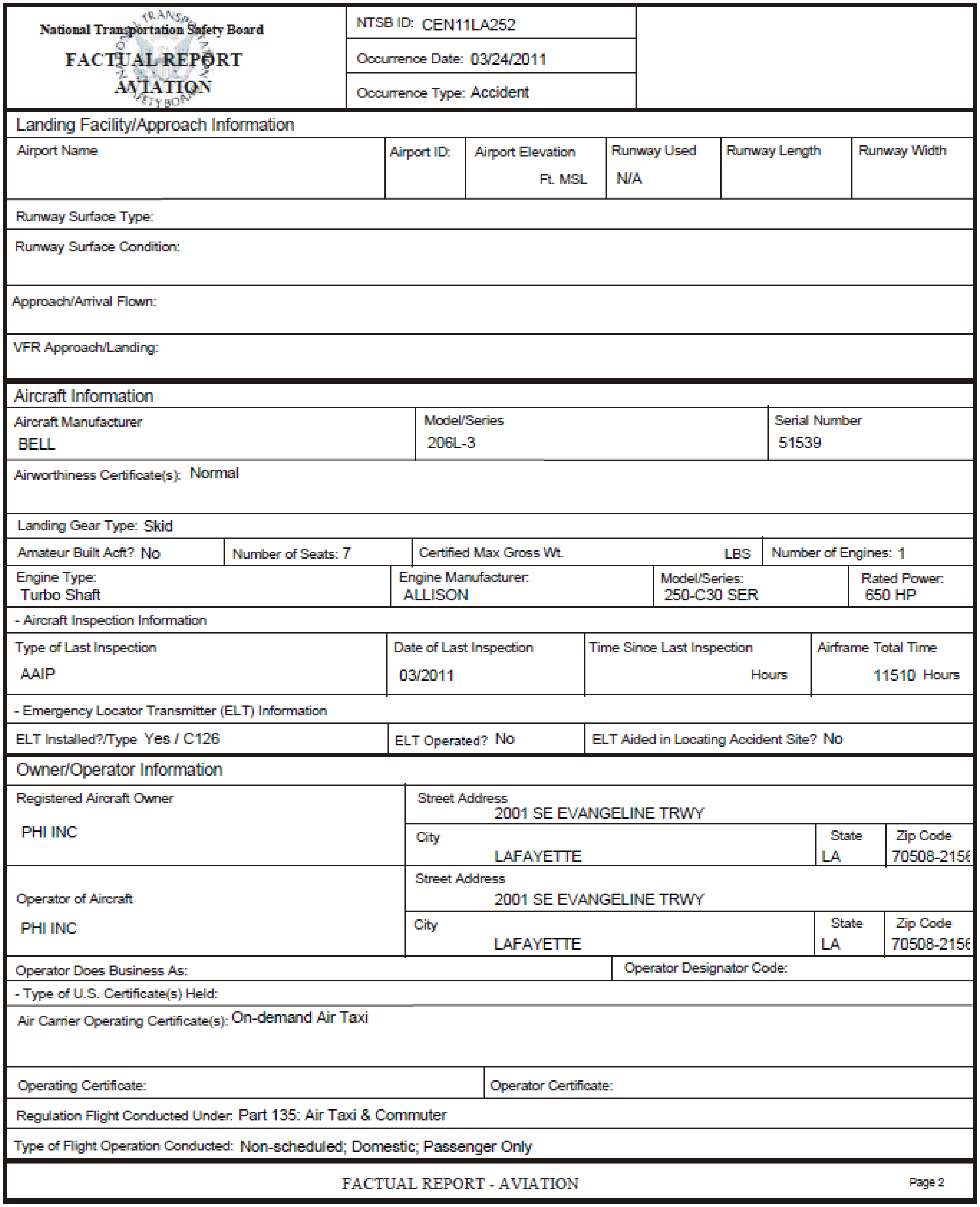
The helicopter was equipped with an Intellistart engine data monitoring system which was downloaded and plotted. A review of the data reveals a slight "spike" on the engine torque and TOT (turbine outlet temperature) readings, which likely occurred at the same time the occupants, heard a loud bang. The chart then depicts the torque and TOT to drop sharply, before a rapid recovery. At the time of the spike, the helicopter's main rotor speed has a slight increase, followed by a decrease, and recovery, before a sudden decrease in main rotor speed. The significant decrease in main rotor rpm is believed to be associated with the main rotor blades impacting the water surface.

The helicopter was equipped with the Apical Industries, Inc. float and life-raft system. An alert service bulletin, SB2010-02, dated 01/18/11, was issued by Apical Industries, Inc. that recognized and addressed a problem with the system's float inflation valve. The operator stated that the service bulletin's updated valve was not installed in the accident helicopter, and would normally be incorporated into the helicopter's regular maintenance schedule. The service bulletin allowed operators until May 1, 2011 to comply with the update.

A review of the Height-Velocity diagram contained in the Bell 206L-3 helicopter's Flight Manual, reveals that at 100 feet above ground level, operations with indicated airspeeds below 51 knots should be avoided. Per the Federal Aviation Administration Rotorcraft Flying Handbook, FAA-H-8083-21, the height/velocity (H/V) diagram depicts critical combinations of airspeed and altitude should an engine failure occur. Operations in crosshatched or shaded areas of the H/V diagram may not allow enough time for the critical transition from powered flight to autorotation. The pilot estimated the height of the helicopter's platform was 100 to 120 feet above the water.
Updated on Aug 15 2012 1:30PM

FACTUAL REPORT - AVIATION

Page 1a



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN11LA252
Occurrence Date: 03/24/2011
Occurrence Type: Accident

Landing Facility/Approach Information

Airport Name	Airport ID:	Airport Elevation Ft. MSL	Runway Used N/A	Runway Length	Runway Width

Runway Surface Type:
Runway Surface Condition:
Approach/Arrival Flown:
VFR Approach/Landing:

Aircraft Information

Aircraft Manufacturer BELL	Model/Series 206L-3	Serial Number 51539

Airworthiness Certificate(s): Normal
Landing Gear Type: Skid

Amateur Built Acft? No	Number of Seats: 7	Certified Max Gross Wt. LBS	Number of Engines: 1
Engine Type: Turbo Shaft	Engine Manufacturer: ALLISON	Model/Series: 250-C30 SER	Rated Power: 650 HP

- Aircraft Inspection Information

Type of Last Inspection AAIP	Date of Last Inspection 03/2011	Time Since Last Inspection Hours	Airframe Total Time 11510 Hours

- Emergency Locator Transmitter (ELT) Information

ELT Installed?/Type Yes / C126	ELT Operated? No	ELT Aided in Locating Accident Site? No

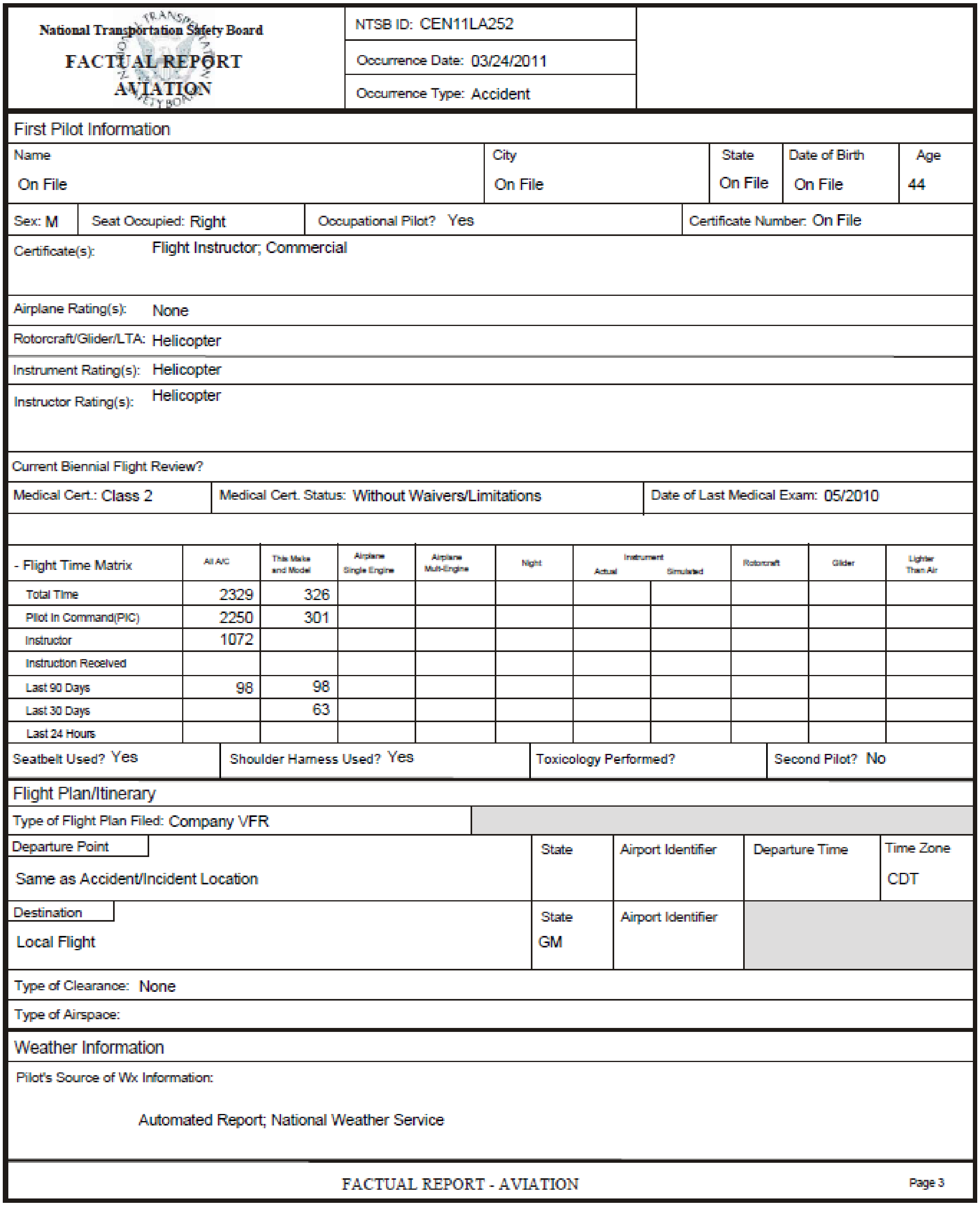
Owner/Operator Information

Registered Aircraft Owner
PHI INC
Street Address
2001 SE EVANGELINE TRWY
City
LAFAYETTE
State
LA
Zip Code
70508-215

Operator of Aircraft
PHI INC
Street Address
2001 SE EVANGELINE TRWY
City
LAFAYETTE
State
LA
Zip Code
70508-215

Operator Does Business As:
Operator Designator Code:
- Type of U.S. Certificate(s) Held:
Air Carrier Operating Certificate(s): On-demand Air Taxi
Operating Certificate:
Operator Certificate:
Regulation Flight Conducted Under: Part 135: Air Taxi & Commuter
Type of Flight Operation Conducted: Non-scheduled; Domestic; Passenger Only

FACTUAL REPORT - AVIATION
Page 2



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN11LA252
Occurrence Date: 03/24/2011
Occurrence Type: Accident

First Pilot Information

Name On File	City On File	State On File	Date of Birth On File	Age 44

Sex: M
Seat Occupied: Right
Occupational Pilot? Yes
Certificate Number: On File

Certificate(s): Flight Instructor; Commercial

Airplane Rating(s): None

Rotorcraft/Glider/LTA: Helicopter

Instrument Rating(s): Helicopter

Instructor Rating(s): Helicopter

Current Biennial Flight Review?

Medical Cert.: Class 2
Medical Cert. Status: Without Waivers/Limitations
Date of Last Medical Exam: 05/2010

- Flight Time Matrix	All A/C	This Make and Model	Airplane Single Engine	Airplane Mult-Engine	Night	Instrument Actual	Instrument Simulated	Rotorcraft	Glider	Lighter Than Air
Total Time	2329	326								
Pilot In Command(PIC)	2250	301								
Instructor	1072									
Instruction Received										
Last 90 Days	98	98								
Last 30 Days		63								
Last 24 Hours										

Seatbelt Used? Yes
Shoulder Harness Used? Yes
Toxicology Performed?
Second Pilot? No

Flight Plan/Itinerary

Type of Flight Plan Filed: Company VFR

Departure Point Same as Accident/Incident Location	State	Airport Identifier	Departure Time	Time Zone CDT
Destination Local Flight	State GM	Airport Identifier		

Type of Clearance: None

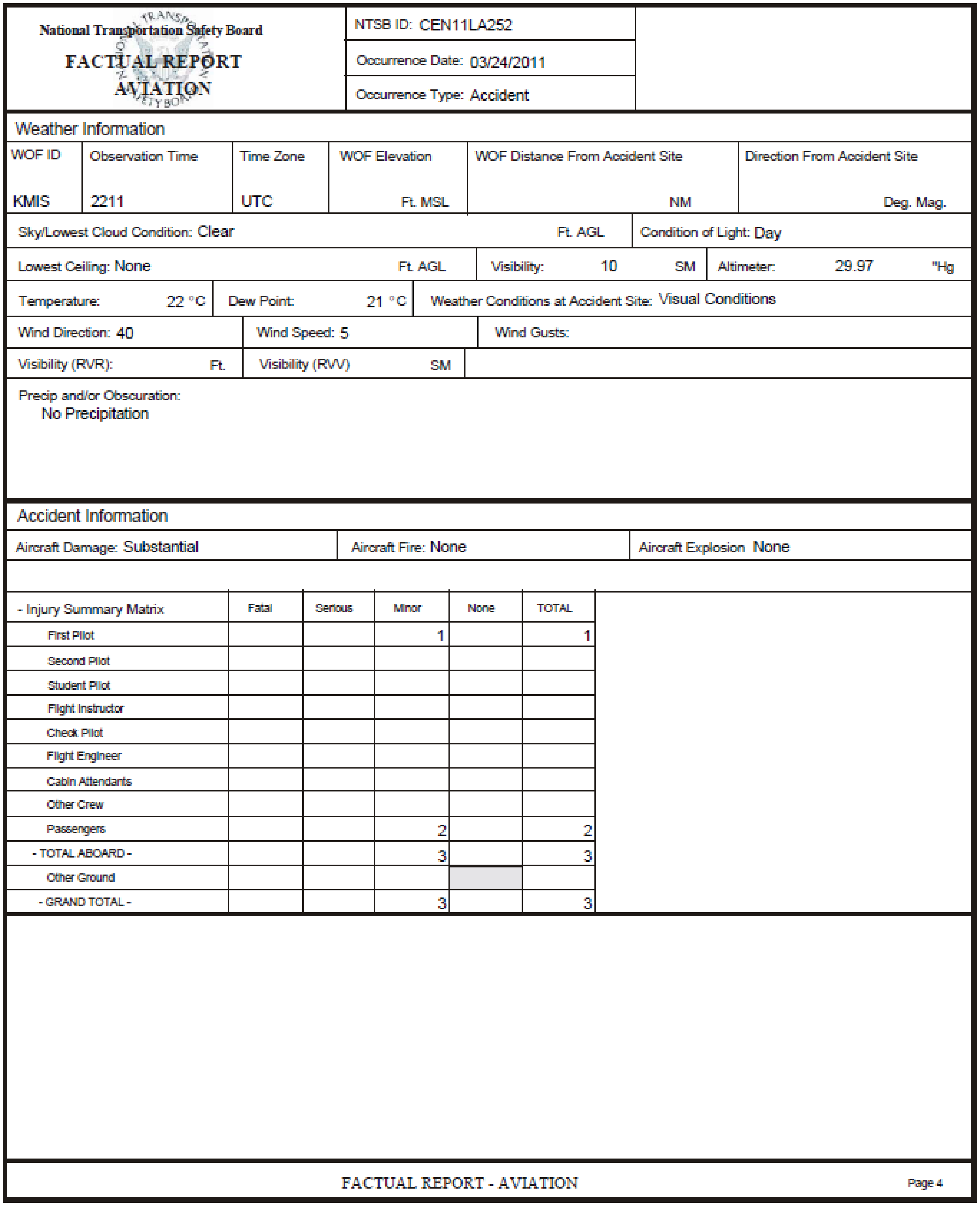
Type of Airspace:

Weather Information

Pilot's Source of Wx Information:

Automated Report; National Weather Service

FACTUAL REPORT - AVIATION
Page 3



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN11LA252
Occurrence Date: 03/24/2011
Occurrence Type: Accident

Weather Information

WOF ID	Observation Time	Time Zone	WOF Elevation	WOF Distance From Accident Site	Direction From Accident Site
KMIS	2211	UTC	Ft. MSL	NM	Deg. Mag.

Sky/Lowest Cloud Condition: Clear Ft. AGL
Condition of Light: Day
Lowest Ceiling: None Ft. AGL
Visibility: 10 SM
Altimeter: 29.97 "Hg
Temperature: 22 °C
Dew Point: 21 °C
Weather Conditions at Accident Site: Visual Conditions
Wind Direction: 40
Wind Speed: 5
Wind Gusts:
Visibility (RVR): Ft.
Visibility (RVV) SM
Precip and/or Obscuration:
No Precipitation

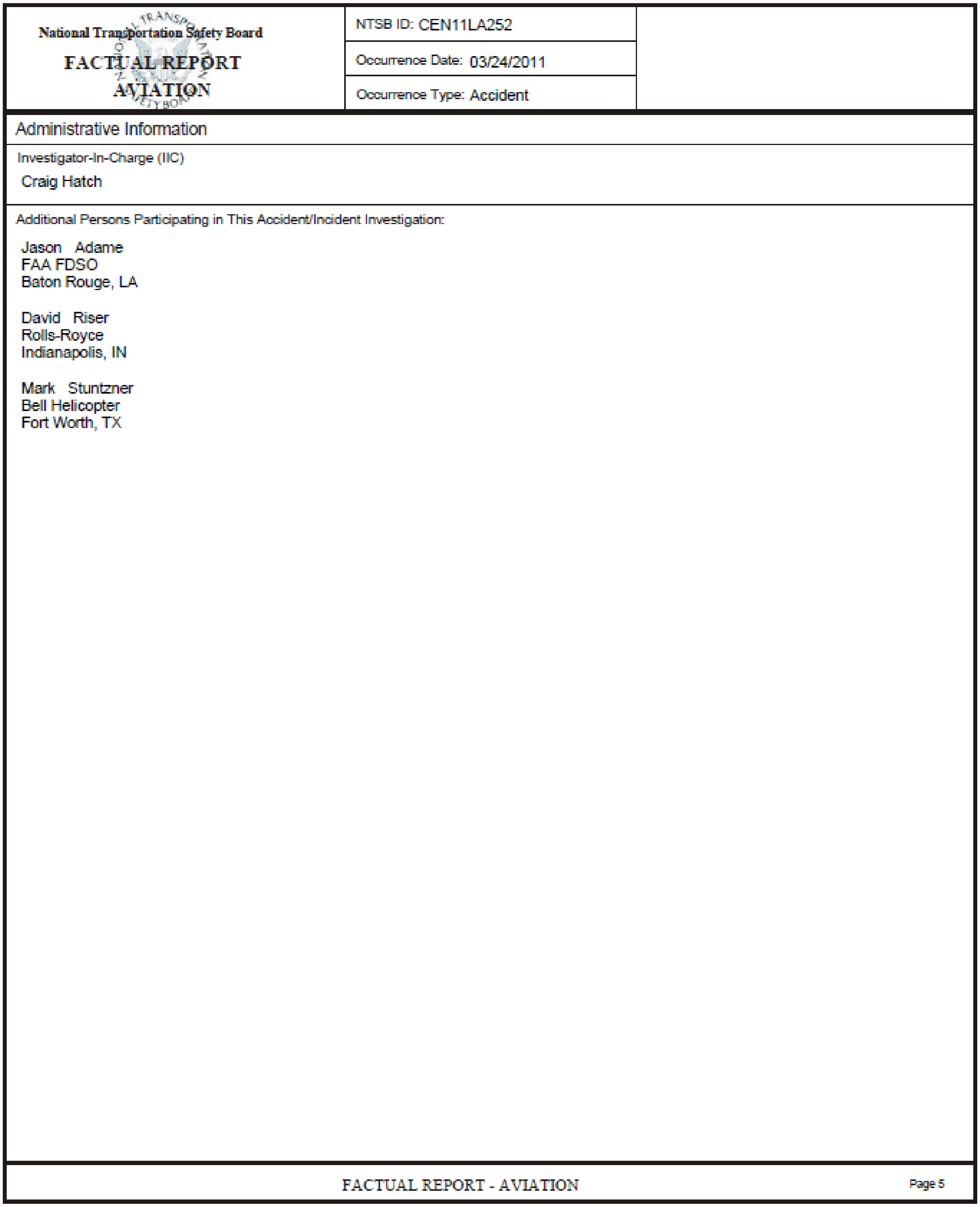
Accident Information

Aircraft Damage: Substantial
Aircraft Fire: None
Aircraft Explosion None

- Injury Summary Matrix	Fatal	Serious	Minor	None	TOTAL
First Pilot			1		1
Second Pilot					
Student Pilot					
Flight Instructor					
Check Pilot					
Flight Engineer					
Cabin Attendants					
Other Crew					
Passengers			2		2
- TOTAL ABOARD -			3		3
Other Ground					
- GRAND TOTAL -			3		3

FACTUAL REPORT - AVIATION

Page 4



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID:	CEN11LA252
Occurrence Date:	03/24/2011
Occurrence Type:	Accident

Administrative Information

Investigator-In-Charge (IIC)

Craig Hatch

Additional Persons Participating in This Accident/Incident Investigation:

Jason Adame
FAA FDSO
Baton Rouge, LA

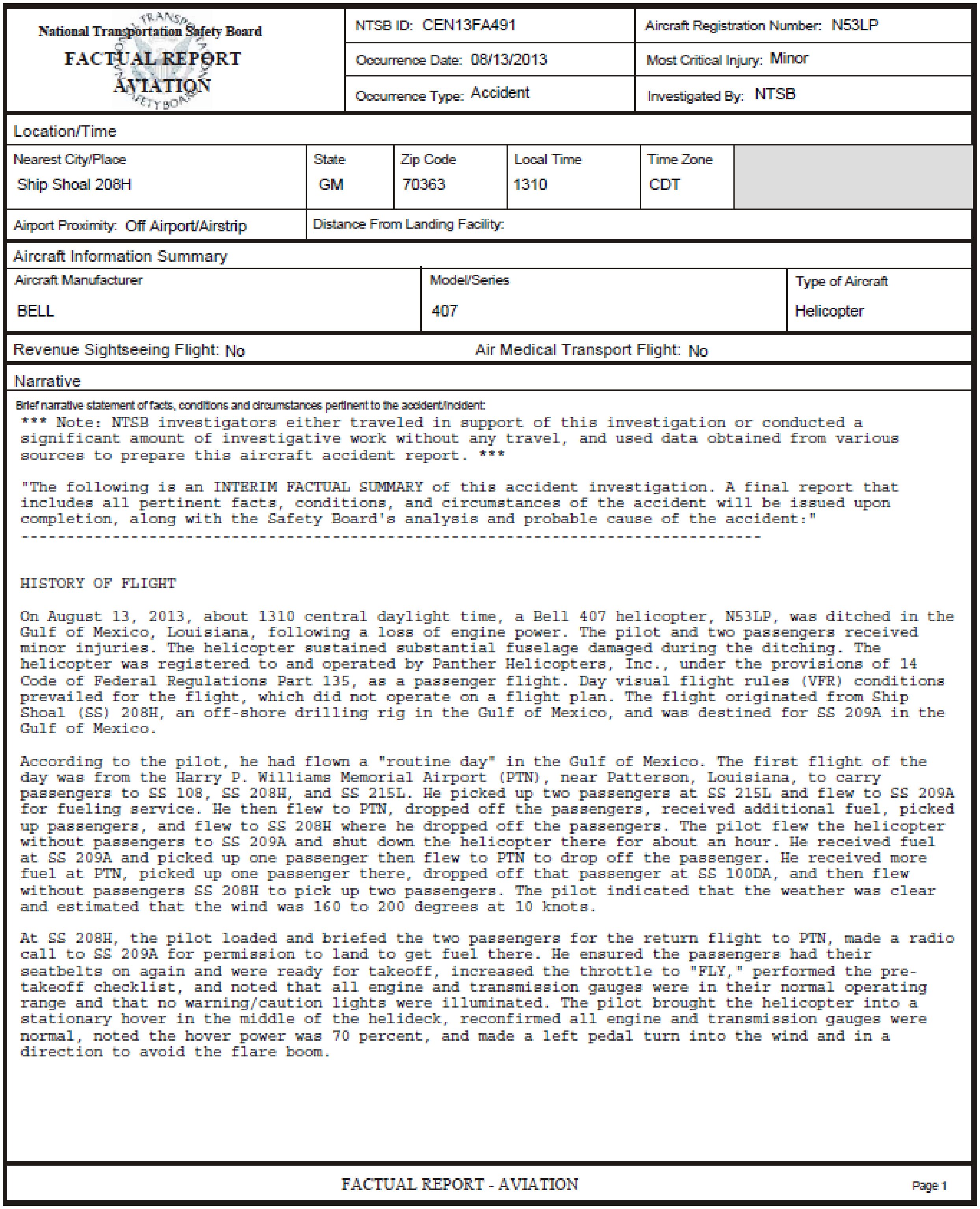
David Riser
Rolls-Royce
Indianapolis, IN

Mark Stuntzner
Bell Helicopter
Fort Worth, TX

FACTUAL REPORT - AVIATION

Page 5

6. *Appendix B-NTSB CEN13FA491*



National Transportation Safety Board **FACTUAL REPORT** **AVIATION**	NTSB ID: CEN13FA491	Aircraft Registration Number: N53LP
	Occurrence Date: 08/13/2013	Most Critical Injury: Minor
	Occurrence Type: Accident	Investigated By: NTSB

Location/Time

Nearest City/Place	State	Zip Code	Local Time	Time Zone
Ship Shoal 208H	GM	70363	1310	CDT

Airport Proximity: Off Airport/Airstrip

Distance From Landing Facility:

Aircraft Information Summary

Aircraft Manufacturer	Model/Series	Type of Aircraft
BELL	407	Helicopter

Revenue Sightseeing Flight: No

Air Medical Transport Flight: No

Narrative

Brief narrative statement of facts, conditions and circumstances pertinent to the accident/incident:

*** Note: NTSB investigators either traveled in support of this investigation or conducted a significant amount of investigative work without any travel, and used data obtained from various sources to prepare this aircraft accident report. ***

"The following is an INTERIM FACTUAL SUMMARY of this accident investigation. A final report that includes all pertinent facts, conditions, and circumstances of the accident will be issued upon completion, along with the Safety Board's analysis and probable cause of the accident:"

HISTORY OF FLIGHT

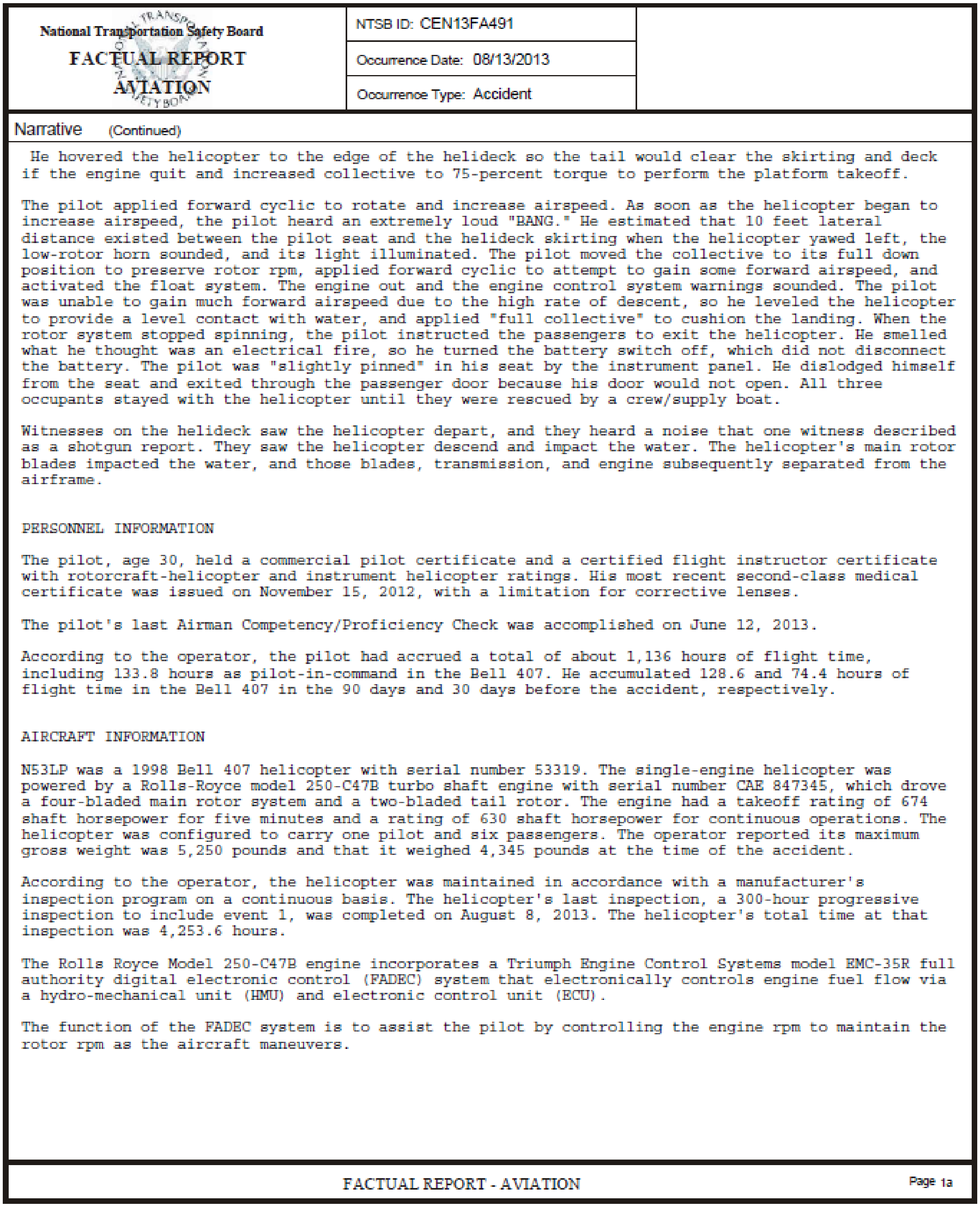
On August 13, 2013, about 1310 central daylight time, a Bell 407 helicopter, N53LP, was ditched in the Gulf of Mexico, Louisiana, following a loss of engine power. The pilot and two passengers received minor injuries. The helicopter sustained substantial fuselage damaged during the ditching. The helicopter was registered to and operated by Panther Helicopters, Inc., under the provisions of 14 Code of Federal Regulations Part 135, as a passenger flight. Day visual flight rules (VFR) conditions prevailed for the flight, which did not operate on a flight plan. The flight originated from Ship Shoal (SS) 208H, an off-shore drilling rig in the Gulf of Mexico, and was destined for SS 209A in the Gulf of Mexico.

According to the pilot, he had flown a "routine day" in the Gulf of Mexico. The first flight of the day was from the Harry P. Williams Memorial Airport (PTN), near Patterson, Louisiana, to carry passengers to SS 108, SS 208H, and SS 215L. He picked up two passengers at SS 215L and flew to SS 209A for fueling service. He then flew to PTN, dropped off the passengers, received additional fuel, picked up passengers, and flew to SS 208H where he dropped off the passengers. The pilot flew the helicopter without passengers to SS 209A and shut down the helicopter there for about an hour. He received fuel at SS 209A and picked up one passenger then flew to PTN to drop off the passenger. He received more fuel at PTN, picked up one passenger there, dropped off that passenger at SS 100DA, and then flew without passengers SS 208H to pick up two passengers. The pilot indicated that the weather was clear and estimated that the wind was 160 to 200 degrees at 10 knots.

At SS 208H, the pilot loaded and briefed the two passengers for the return flight to PTN, made a radio call to SS 209A for permission to land to get fuel there. He ensured the passengers had their seatbelts on again and were ready for takeoff, increased the throttle to "FLY," performed the pre-takeoff checklist, and noted that all engine and transmission gauges were in their normal operating range and that no warning/caution lights were illuminated. The pilot brought the helicopter into a stationary hover in the middle of the helideck, reconfirmed all engine and transmission gauges were normal, noted the hover power was 70 percent, and made a left pedal turn into the wind and in a direction to avoid the flare boom.

FACTUAL REPORT - AVIATION

Page 1



National Transportation Safety Board **FACTUAL REPORT** **AVIATION**	NTSB ID: CEN13FA491 Occurrence Date: 08/13/2013 Occurrence Type: Accident	

Narrative (Continued)

He hovered the helicopter to the edge of the helideck so the tail would clear the skirting and deck if the engine quit and increased collective to 75-percent torque to perform the platform takeoff.

The pilot applied forward cyclic to rotate and increase airspeed. As soon as the helicopter began to increase airspeed, the pilot heard an extremely loud "BANG." He estimated that 10 feet lateral distance existed between the pilot seat and the helideck skirting when the helicopter yawed left, the low-rotor horn sounded, and its light illuminated. The pilot moved the collective to its full down position to preserve rotor rpm, applied forward cyclic to attempt to gain some forward airspeed, and activated the float system. The engine out and the engine control system warnings sounded. The pilot was unable to gain much forward airspeed due to the high rate of descent, so he leveled the helicopter to provide a level contact with water, and applied "full collective" to cushion the landing. When the rotor system stopped spinning, the pilot instructed the passengers to exit the helicopter. He smelled what he thought was an electrical fire, so he turned the battery switch off, which did not disconnect the battery. The pilot was "slightly pinned" in his seat by the instrument panel. He dislodged himself from the seat and exited through the passenger door because his door would not open. All three occupants stayed with the helicopter until they were rescued by a crew/supply boat.

Witnesses on the helideck saw the helicopter depart, and they heard a noise that one witness described as a shotgun report. They saw the helicopter descend and impact the water. The helicopter's main rotor blades impacted the water, and those blades, transmission, and engine subsequently separated from the airframe.

PERSONNEL INFORMATION

The pilot, age 30, held a commercial pilot certificate and a certified flight instructor certificate with rotorcraft-helicopter and instrument helicopter ratings. His most recent second-class medical certificate was issued on November 15, 2012, with a limitation for corrective lenses.

The pilot's last Airman Competency/Proficiency Check was accomplished on June 12, 2013.

According to the operator, the pilot had accrued a total of about 1,136 hours of flight time, including 133.8 hours as pilot-in-command in the Bell 407. He accumulated 128.6 and 74.4 hours of flight time in the Bell 407 in the 90 days and 30 days before the accident, respectively.

AIRCRAFT INFORMATION

N53LP was a 1998 Bell 407 helicopter with serial number 53319. The single-engine helicopter was powered by a Rolls-Royce model 250-C47B turbo shaft engine with serial number CAE 847345, which drove a four-bladed main rotor system and a two-bladed tail rotor. The engine had a takeoff rating of 674 shaft horsepower for five minutes and a rating of 630 shaft horsepower for continuous operations. The helicopter was configured to carry one pilot and six passengers. The operator reported its maximum gross weight was 5,250 pounds and that it weighed 4,345 pounds at the time of the accident.

According to the operator, the helicopter was maintained in accordance with a manufacturer's inspection program on a continuous basis. The helicopter's last inspection, a 300-hour progressive inspection to include event 1, was completed on August 8, 2013. The helicopter's total time at that inspection was 4,253.6 hours.

The Rolls Royce Model 250-C47B engine incorporates a Triumph Engine Control Systems model EMC-35R full authority digital electronic control (FADEC) system that electronically controls engine fuel flow via a hydro-mechanical unit (HMU) and electronic control unit (ECU).

The function of the FADEC system is to assist the pilot by controlling the engine rpm to maintain the rotor rpm as the aircraft maneuvers.

FACTUAL REPORT - AVIATION Page 1a

National Transportation Safety Board **FACTUAL REPORT** **AVIATION**	NTSB ID: CEN13FA491 Occurrence Date: 08/13/2013 Occurrence Type: Accident

Narrative (Continued)

At any time, the pilot may de-select the FADEC system and acquire complete control of engine fuel modulation (a back-up mode of operation).

The FADEC ECU contains two embedded processor systems that execute application-specific engine control software. The primary system operates by sensing the pilot-controlled collective twist-grip throttle position (Power Lever Angle [PLA]), as well as other engine sensor inputs, to determine the engine fuel flow requirements necessary to maintain efficient engine operation. The reversionary system is a second level of electronic fuel control governing that would be automatically switched to should certain fault conditions be detected in the primary system. Both the ECU primary and reversionary systems control an electric motor in the HMU that modulates fuel flow to the engine.

In addition, the FADEC ECU monitors engine condition and records and stores engine operating exceedances and system fault information in a non-volatile memory device in the ECU. For certain system failures, the FADEC systems will automatically de-select the FADEC operation and transition to back-up (pilot control) operation.

The HMU consists of a gearbox-mounted fuel pump, a motor driven fuel metering valve, a back-up fuel control system, a PLA input shaft, and feedback position sensors. The HMU contains components that send/receive electrical signals to/from the ECU as a part of the FADEC operation and is the point of fuel flow in the FADEC or back-up modes of operation.

METEOROLOGICAL INFORMATION

At 1250, the recorded weather 63 nautical miles and 12 degrees from the accident site, at the Houma-Terrebonne Airport, near Houma, Louisiana, was: wind 210 degrees at 8 knots; visibility 5 statute miles; present weather rain and mist; sky condition broken clouds at 3,400 feet; temperature 29 degrees C; dew point 33 degrees C; altimeter 30.04 inches of mercury.

AIRPORT INFORMATION

According to the Bureau of Safety and Environmental Enforcement, the Gulf of Mexico is divided into three primary subdivisions: Western Gulf of Mexico, Central Gulf of Mexico, and Eastern Gulf of Mexico. The three subdivisions are further divided into areas and blocks. The blocks are about 3 miles long and 3 miles wide and are used to reference oil/gas lease identification. There are over 2,600 offshore production platforms in the Gulf of Mexico region.

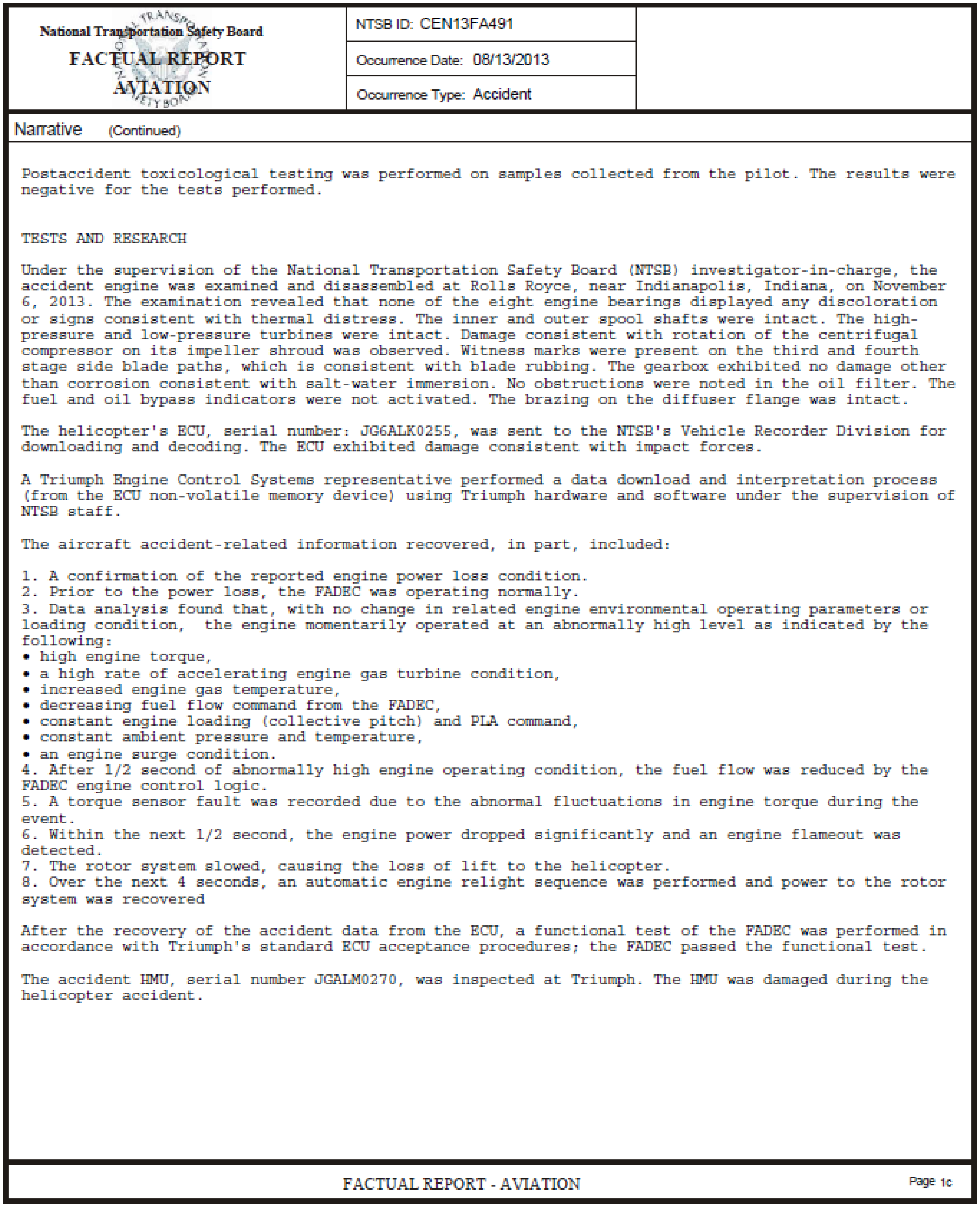
SS 208H is an offshore platform (latitude: 28 degrees 32 minutes north; longitude: 90 degrees 55 minutes west) about 74.5 nm southeast of Patterson, Louisiana. SS 208H features a single helideck (about 24 feet long and 24 feet wide) outlined by a painted red line and owner identification in the center.

SS 209A is an offshore platform (latitude: 28 degrees 31 minutes north; longitude: 90 degrees 52 minutes west) about 75.5 nm southeast of Patterson, Louisiana. SS 209A features a single helideck (approximately 40 feet long and 52 feet wide) outlined by a painted red line and owner identification in the center.

WRECKAGE AND IMPACT INFORMATION

The helicopter's tailcone remained attached to the fuselage and the engine and transmission had separated from the fuselage. Large components of the helicopter were recovered from the surface of the water and brought to shore. The engine was located underwater near the accident site. It was recovered to a ship and also brought to shore. The transmission was not recovered. Images from the recovery showed that a float bag exhibited a puncture.

MEDICAL AND PATHOLOGICAL INFORMATION



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN13FA491
Occurrence Date: 08/13/2013
Occurrence Type: Accident

Narrative (Continued)

Postaccident toxicological testing was performed on samples collected from the pilot. The results were negative for the tests performed.

TESTS AND RESEARCH

Under the supervision of the National Transportation Safety Board (NTSB) investigator-in-charge, the accident engine was examined and disassembled at Rolls Royce, near Indianapolis, Indiana, on November 6, 2013. The examination revealed that none of the eight engine bearings displayed any discoloration or signs consistent with thermal distress. The inner and outer spool shafts were intact. The high-pressure and low-pressure turbines were intact. Damage consistent with rotation of the centrifugal compressor on its impeller shroud was observed. Witness marks were present on the third and fourth stage side blade paths, which is consistent with blade rubbing. The gearbox exhibited no damage other than corrosion consistent with salt-water immersion. No obstructions were noted in the oil filter. The fuel and oil bypass indicators were not activated. The brazing on the diffuser flange was intact.

The helicopter's ECU, serial number: JG6ALK0255, was sent to the NTSB's Vehicle Recorder Division for downloading and decoding. The ECU exhibited damage consistent with impact forces.

A Triumph Engine Control Systems representative performed a data download and interpretation process (from the ECU non-volatile memory device) using Triumph hardware and software under the supervision of NTSB staff.

The aircraft accident-related information recovered, in part, included:

1. A confirmation of the reported engine power loss condition.
2. Prior to the power loss, the FADEC was operating normally.
3. Data analysis found that, with no change in related engine environmental operating parameters or loading condition, the engine momentarily operated at an abnormally high level as indicated by the following:
- high engine torque,
- a high rate of accelerating engine gas turbine condition,
- increased engine gas temperature,
- decreasing fuel flow command from the FADEC,
- constant engine loading (collective pitch) and PLA command,
- constant ambient pressure and temperature,
- an engine surge condition.

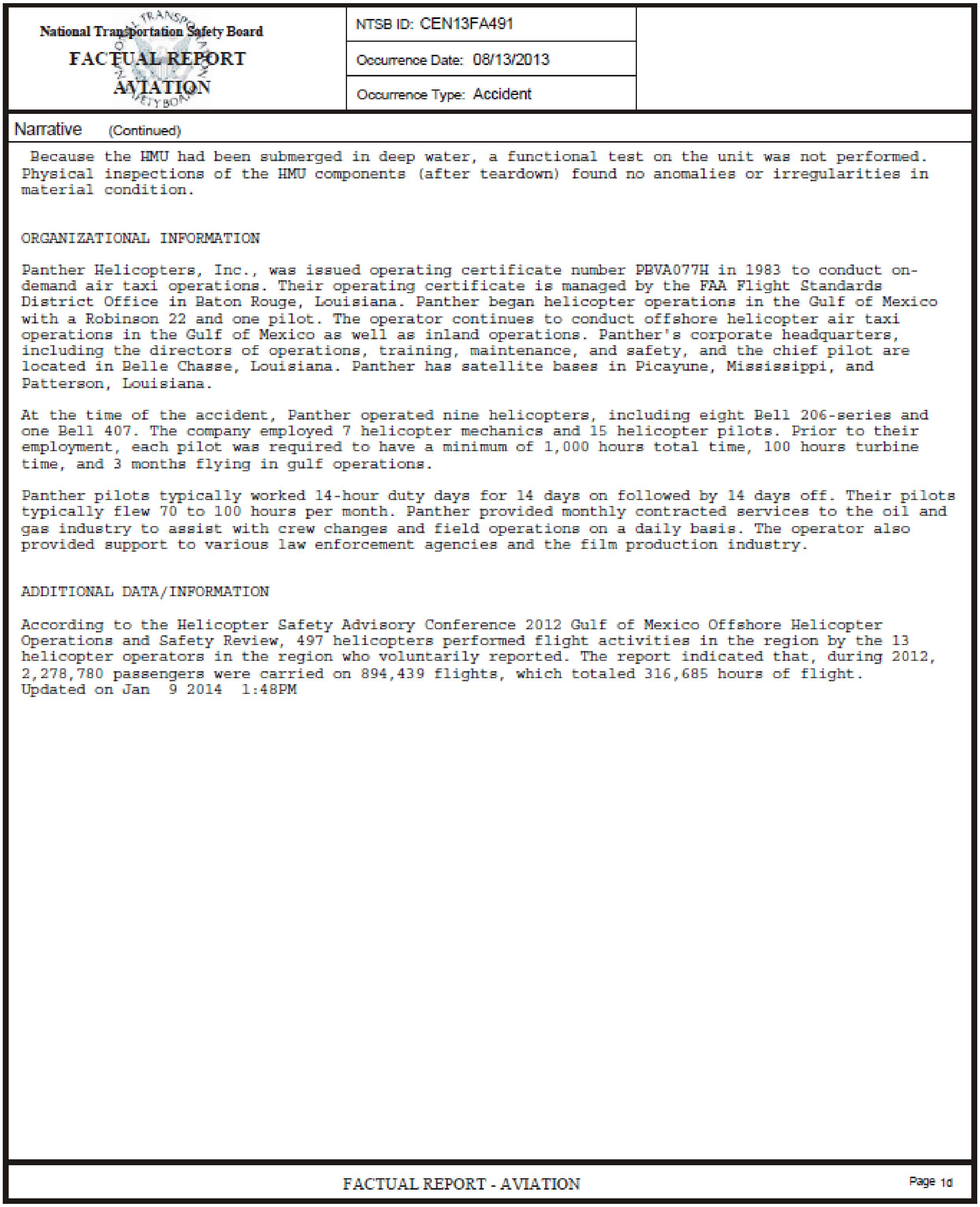
4. After 1/2 second of abnormally high engine operating condition, the fuel flow was reduced by the FADEC engine control logic.
5. A torque sensor fault was recorded due to the abnormal fluctuations in engine torque during the event.
6. Within the next 1/2 second, the engine power dropped significantly and an engine flameout was detected.
7. The rotor system slowed, causing the loss of lift to the helicopter.
8. Over the next 4 seconds, an automatic engine relight sequence was performed and power to the rotor system was recovered

After the recovery of the accident data from the ECU, a functional test of the FADEC was performed in accordance with Triumph's standard ECU acceptance procedures; the FADEC passed the functional test.

The accident HMU, serial number JGALM0270, was inspected at Triumph. The HMU was damaged during the helicopter accident.

FACTUAL REPORT - AVIATION

Page 1c



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN13FA491

Occurrence Date: 08/13/2013

Occurrence Type: Accident

Narrative (Continued)

Because the HMU had been submerged in deep water, a functional test on the unit was not performed. Physical inspections of the HMU components (after teardown) found no anomalies or irregularities in material condition.

ORGANIZATIONAL INFORMATION

Panther Helicopters, Inc., was issued operating certificate number PBVA077H in 1983 to conduct on-demand air taxi operations. Their operating certificate is managed by the FAA Flight Standards District Office in Baton Rouge, Louisiana. Panther began helicopter operations in the Gulf of Mexico with a Robinson 22 and one pilot. The operator continues to conduct offshore helicopter air taxi operations in the Gulf of Mexico as well as inland operations. Panther's corporate headquarters, including the directors of operations, training, maintenance, and safety, and the chief pilot are located in Belle Chasse, Louisiana. Panther has satellite bases in Picayune, Mississippi, and Patterson, Louisiana.

At the time of the accident, Panther operated nine helicopters, including eight Bell 206-series and one Bell 407. The company employed 7 helicopter mechanics and 15 helicopter pilots. Prior to their employment, each pilot was required to have a minimum of 1,000 hours total time, 100 hours turbine time, and 3 months flying in gulf operations.

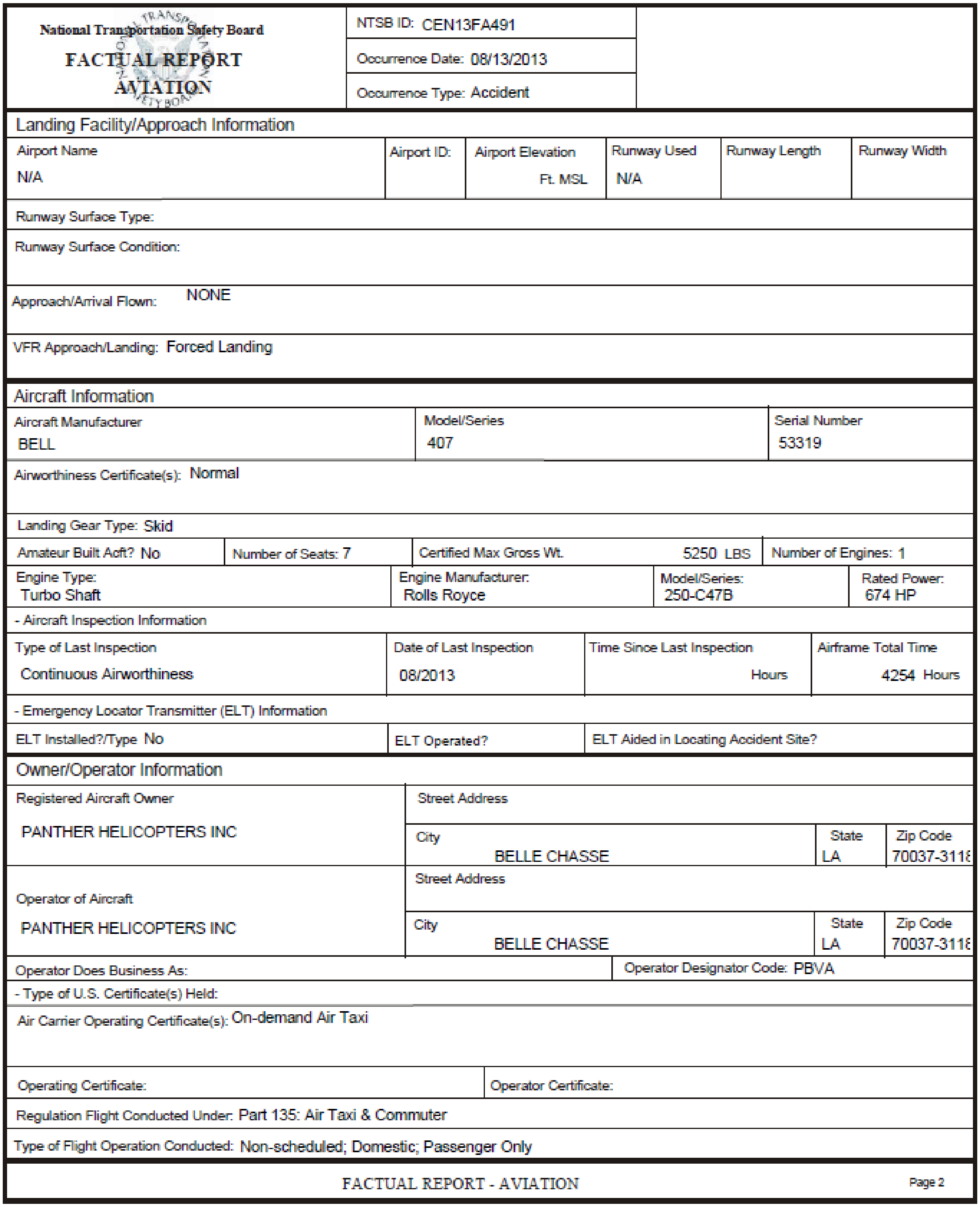
Panther pilots typically worked 14-hour duty days for 14 days on followed by 14 days off. Their pilots typically flew 70 to 100 hours per month. Panther provided monthly contracted services to the oil and gas industry to assist with crew changes and field operations on a daily basis. The operator also provided support to various law enforcement agencies and the film production industry.

ADDITIONAL DATA/INFORMATION

According to the Helicopter Safety Advisory Conference 2012 Gulf of Mexico Offshore Helicopter Operations and Safety Review, 497 helicopters performed flight activities in the region by the 13 helicopter operators in the region who voluntarily reported. The report indicated that, during 2012, 2,278,780 passengers were carried on 894,439 flights, which totaled 316,685 hours of flight.
Updated on Jan 9 2014 1:48PM

FACTUAL REPORT - AVIATION

Page 1d



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN13FA491
Occurrence Date: 08/13/2013
Occurrence Type: Accident

Landing Facility/Approach Information

Airport Name	Airport ID:	Airport Elevation	Runway Used	Runway Length	Runway Width
N/A		Ft. MSL	N/A		

Runway Surface Type:
Runway Surface Condition:
Approach/Arrival Flown: NONE
VFR Approach/Landing: Forced Landing

Aircraft Information

Aircraft Manufacturer	Model/Series	Serial Number
BELL	407	53319

Airworthiness Certificate(s): Normal
Landing Gear Type: Skid

Amateur Built Acft? No	Number of Seats: 7	Certified Max Gross Wt. 5250 LBS	Number of Engines: 1

Engine Type:	Engine Manufacturer:	Model/Series:	Rated Power:
Turbo Shaft	Rolls Royce	250-C47B	674 HP

- Aircraft Inspection Information

Type of Last Inspection	Date of Last Inspection	Time Since Last Inspection	Airframe Total Time
Continuous Airworthiness	08/2013	Hours	4254 Hours

- Emergency Locator Transmitter (ELT) Information

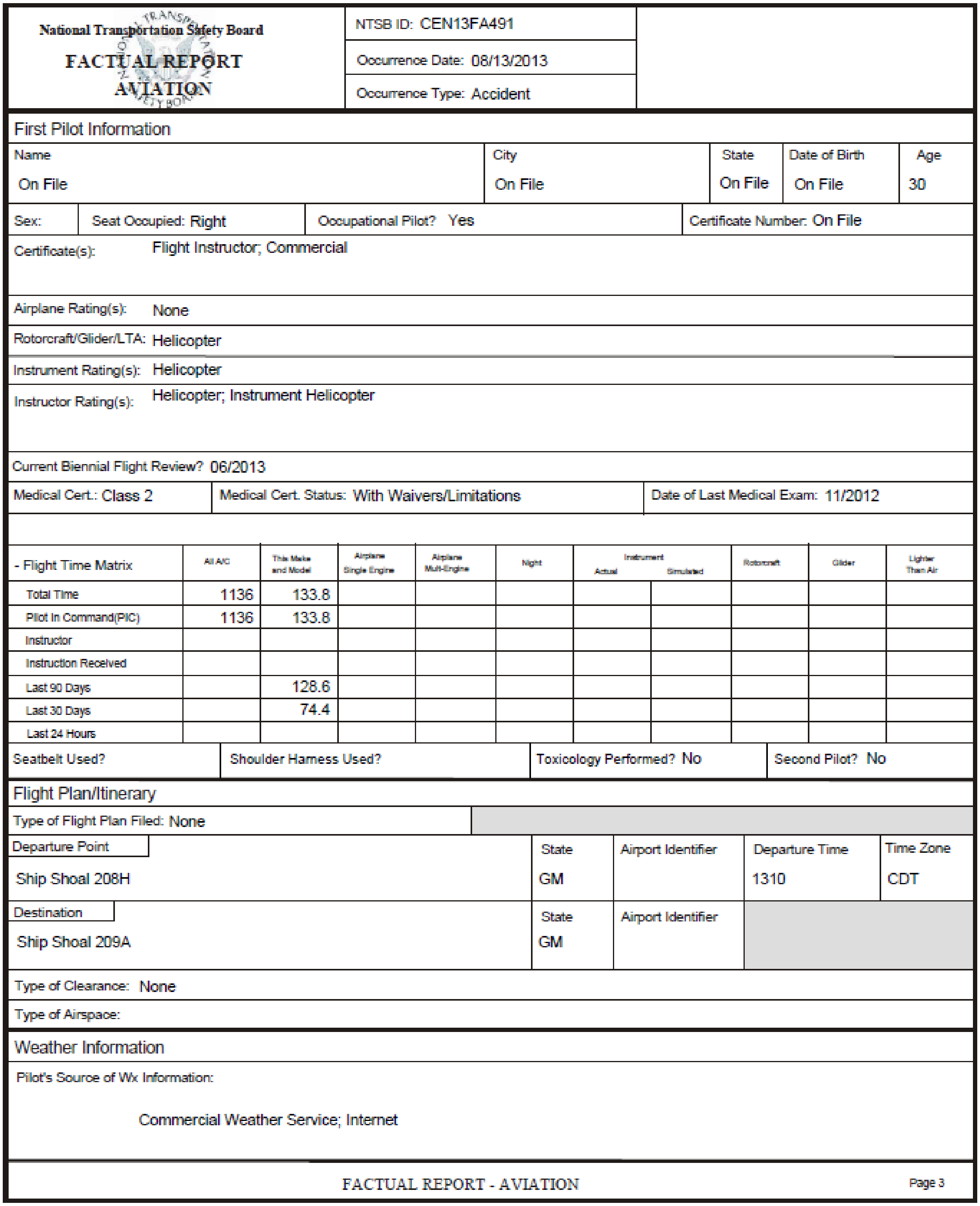
ELT Installed?/Type No	ELT Operated?	ELT Aided in Locating Accident Site?

Owner/Operator Information

Registered Aircraft Owner	Street Address			
PANTHER HELICOPTERS INC	City	BELLE CHASSE	State LA	Zip Code 70037-311
Operator of Aircraft	Street Address			
PANTHER HELICOPTERS INC	City	BELLE CHASSE	State LA	Zip Code 70037-311

Operator Does Business As:
Operator Designator Code: PBVA
- Type of U.S. Certificate(s) Held:
Air Carrier Operating Certificate(s): On-demand Air Taxi
Operating Certificate:
Operator Certificate:
Regulation Flight Conducted Under: Part 135: Air Taxi & Commuter
Type of Flight Operation Conducted: Non-scheduled; Domestic; Passenger Only

FACTUAL REPORT - AVIATION
Page 2



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN13FA491
Occurrence Date: 08/13/2013
Occurrence Type: Accident

First Pilot Information

Name On File	City On File	State On File	Date of Birth On File	Age 30

Sex:
Seat Occupied: Right
Occupational Pilot? Yes
Certificate Number: On File

Certificate(s): Flight Instructor; Commercial

Airplane Rating(s): None

Rotorcraft/Glider/LTA: Helicopter

Instrument Rating(s): Helicopter

Instructor Rating(s): Helicopter; Instrument Helicopter

Current Biennial Flight Review? 06/2013

Medical Cert.: Class 2
Medical Cert. Status: With Waivers/Limitations
Date of Last Medical Exam: 11/2012

- Flight Time Matrix	All A/C	This Make and Model	Airplane Single Engine	Airplane Mult-Engine	Night	Instrument Actual	Instrument Simulated	Rotorcraft	Glider	Lighter Than Air
Total Time	1136	133.8								
Pilot In Command(PIC)	1136	133.8								
Instructor										
Instruction Received										
Last 90 Days		128.6								
Last 30 Days		74.4								
Last 24 Hours										

Seatbelt Used?
Shoulder Harness Used?
Toxicology Performed? No
Second Pilot? No

Flight Plan/Itinerary

Type of Flight Plan Filed: None

Departure Point Ship Shoal 208H	State GM	Airport Identifier	Departure Time 1310	Time Zone CDT
Destination Ship Shoal 209A	State GM	Airport Identifier		

Type of Clearance: None

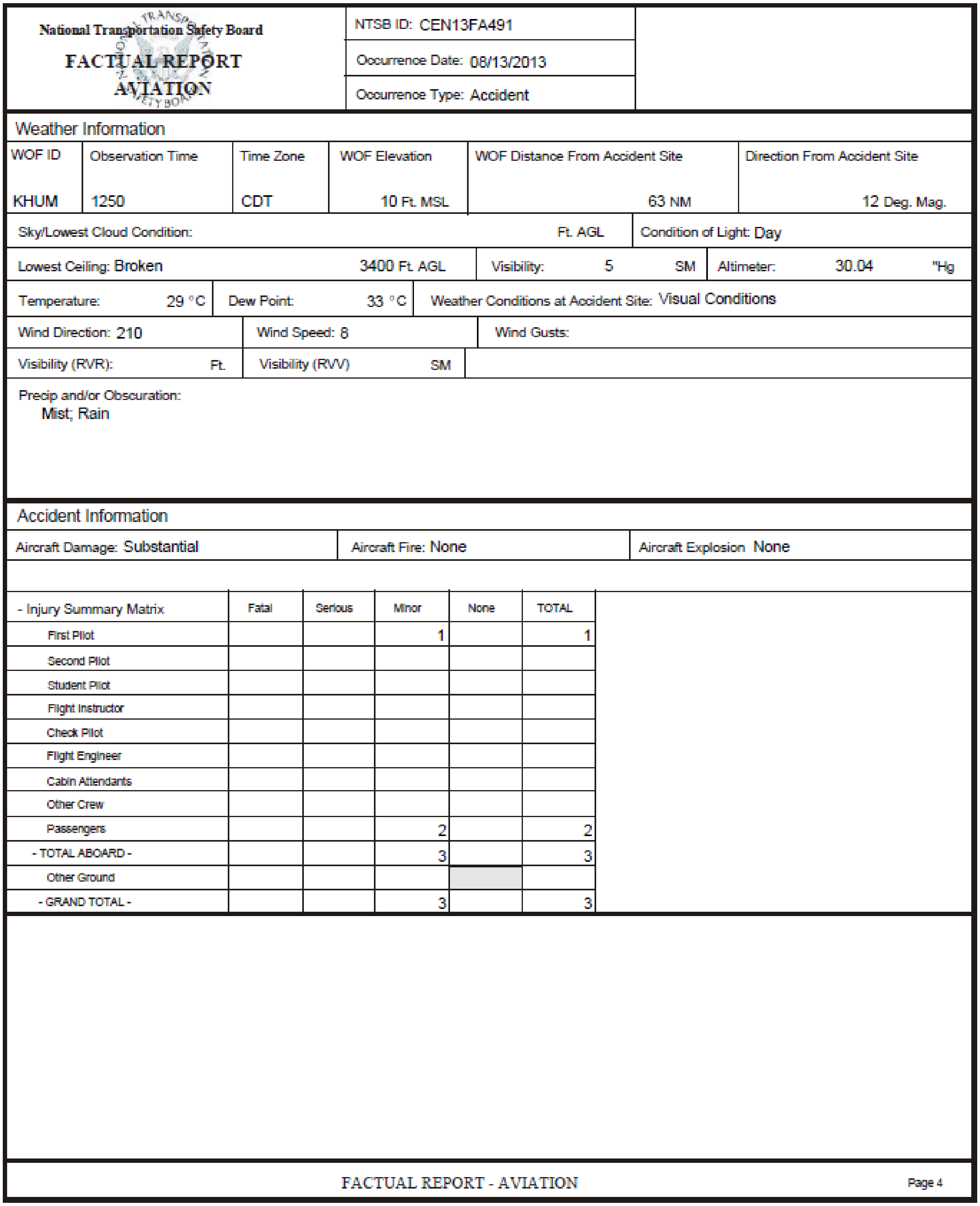
Type of Airspace:

Weather Information

Pilot's Source of Wx Information:

Commercial Weather Service; Internet

FACTUAL REPORT - AVIATION
Page 3



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN13FA491
Occurrence Date: 08/13/2013
Occurrence Type: Accident

Weather Information

WOF ID	Observation Time	Time Zone	WOF Elevation	WOF Distance From Accident Site	Direction From Accident Site
KHUM	1250	CDT	10 Ft. MSL	63 NM	12 Deg. Mag.

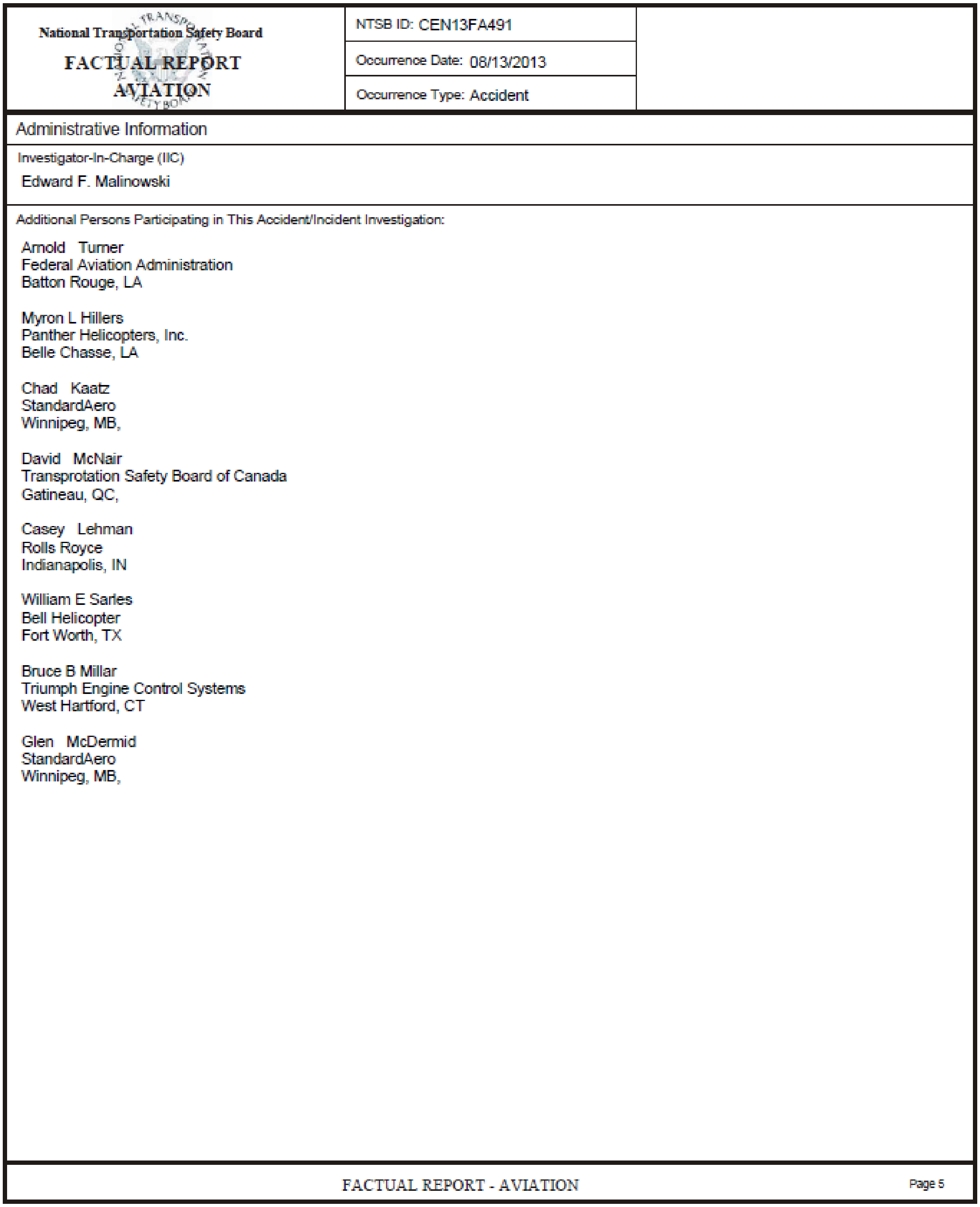
Sky/Lowest Cloud Condition: Ft. AGL
Condition of Light: Day
Lowest Ceiling: Broken 3400 Ft. AGL
Visibility: 5 SM
Altimeter: 30.04 "Hg
Temperature: 29 °C
Dew Point: 33 °C
Weather Conditions at Accident Site: Visual Conditions
Wind Direction: 210
Wind Speed: 8
Wind Gusts:
Visibility (RVR): Ft.
Visibility (RVV) SM
Precip and/or Obscuration:
Mist; Rain

Accident Information

Aircraft Damage: Substantial
Aircraft Fire: None
Aircraft Explosion None

- Injury Summary Matrix	Fatal	Serious	Minor	None	TOTAL
First Pilot			1		1
Second Pilot					
Student Pilot					
Flight Instructor					
Check Pilot					
Flight Engineer					
Cabin Attendants					
Other Crew					
Passengers			2		2
- TOTAL ABOARD -			3		3
Other Ground					
- GRAND TOTAL -			3		3

FACTUAL REPORT - AVIATION Page 4



National Transportation Safety Board
FACTUAL REPORT
AVIATION

NTSB ID: CEN13FA491

Occurrence Date: 08/13/2013

Occurrence Type: Accident

Administrative Information

Investigator-In-Charge (IIC)

Edward F. Malinowski

Additional Persons Participating in This Accident/Incident Investigation:

Arnold Turner
Federal Aviation Administration
Batton Rouge, LA

Myron L Hillers
Panther Helicopters, Inc.
Belle Chasse, LA

Chad Kaatz
StandardAero
Winnipeg, MB,

David McNair
Transprotation Safety Board of Canada
Gatineau, QC,

Casey Lehman
Rolls Royce
Indianapolis, IN

William E Sarles
Bell Helicopter
Fort Worth, TX

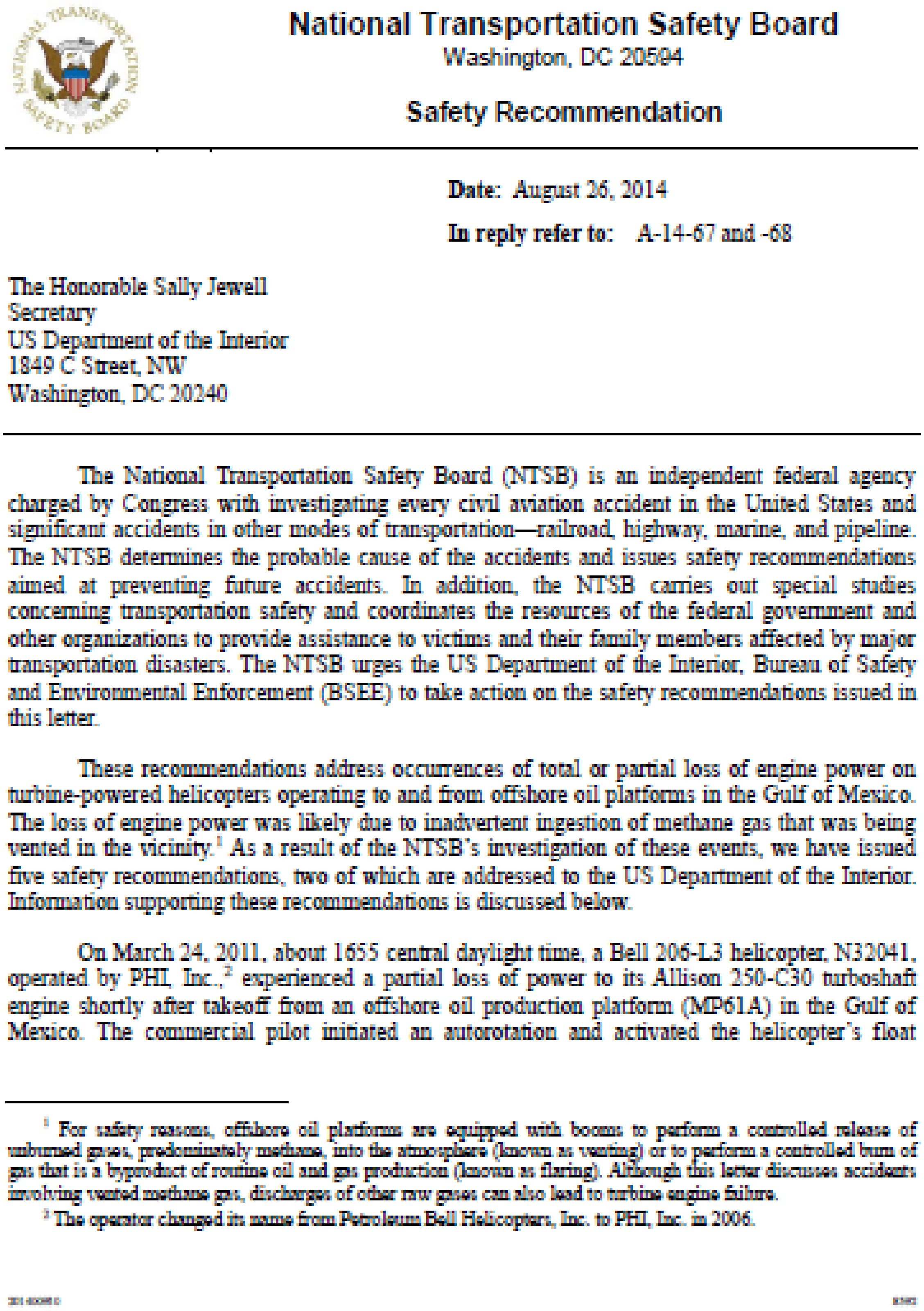
Bruce B Millar
Triumph Engine Control Systems
West Hartford, CT

Glen McDermid
StandardAero
Winnipeg, MB,

FACTUAL REPORT - AVIATION

Page 5

7. *Appendix C-NTSB Safety Recommendations A-14-67-through 71*



National Transportation Safety Board
Washington, DC 20594

Safety Recommendation

Date: August 26, 2014

In reply to refer to: A-14-67 and -68

The Honorable Sally Jewell
Secretary
US Department of the Interior
1849 C Street, NW
Washington, DC 20240

The National Transportation Safety Board (NTSB) is an independent federal agency charged by Congress with investigating every civil aviation accident in the United States and significant accidents in other modes of transportation—railroad, highway, marine, and pipeline. The NTSB determines the probable cause of the accidents and issues safety recommendations aimed at preventing future accidents. In addition, the NTSB carries out special studies concerning transportation safety and coordinates the resources of the federal government and other organizations to provide assistance to victims and their family members affected by major transportation disasters. The NTSB urges the US Department of the Interior, Bureau of Safety and Environmental Enforcement (BSEE) to take action on the safety recommendations issued in this letter.

These recommendations address occurrences of total or partial loss of engine power on turbine-powered helicopters operating to and from offshore oil platforms in the Gulf of Mexico. The loss of engine power was likely due to inadvertent ingestion of methane gas that was being vented in the vicinity.[1] As a result of the NTSB's investigation of these events, we have issued five safety recommendations, two of which are addressed to the US Department of the Interior. Information supporting these recommendations is discussed below.

On March 24, 2011, about 1655 central daylight time, a Bell 206-L3 helicopter, N32041, operated by PHI, Inc.,[2] experienced a partial loss of power to its Allison 250-C30 turboshaft engine shortly after takeoff from an offshore oil production platform (MP61A) in the Gulf of Mexico. The commercial pilot initiated an autorotation and activated the helicopter's float

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[1] For safety reasons, offshore oil platforms are equipped with booms to perform a controlled release of unburned gases, predominately methane, into the atmosphere (known as venting) or to perform a controlled burn of gas that is a byproduct of routine oil and gas production (known as flaring). Although this letter discusses accidents involving vented methane gas, discharges of other raw gases can also lead to turbine engine failure.

[2] The operator changed its name from Petroleum Bell Helicopters, Inc. to PHI, Inc. in 2006.

system; the helicopter impacted the water and rolled inverted. The pilot and two passengers received minor injuries, and the helicopter was substantially damaged.[3]

The pilot and passengers reported hearing a loud bang just after the helicopter departed the platform toward the northwest into the wind. After hearing the bang, the pilot observed a high indication on the torque gauge but did not note any other gauge readings before initiating the autorotation. He stated that when the bang sounded, the helicopter was above and just beyond an "exhaust pipe" on the platform but that he did not know what it vented or whether it was venting when he took off. The production foreman on the platform later reported that the flare boom was venting methane throughout the day, including at the time of the helicopter's departure. The platform was not equipped to provide any visual indication to pilots when gas was venting. Review of data from the helicopter's engine data monitoring system revealed a slight increase in the engine torque and turbine outlet temperature readings. Examination of the engine revealed no anomalies that would result in a loss of power. The NTSB determined the probable cause of this accident was "the loss of engine power due to an engine compressor stall as a result of ingesting methane gas during takeoff."

On August 13, 2013, a Bell 407 helicopter, N53LP, operated by Panther Helicopters, Inc., experienced a total loss of power to its Rolls-Royce 250-C47B turboshaft engine shortly after takeoff from an offshore oil platform (SS208H) in the Gulf of Mexico. The pilot reported hearing a loud bang and attempted to increase the helicopter's forward airspeed but was unable. He then took mitigating actions once impact with the water was imminent. The pilot and two passengers sustained minor injuries, and the helicopter was substantially damaged.[4]

The NTSB's investigation of the 2013 accident is ongoing. Preliminary analysis of data from the helicopter's full authority digital electronic control system indicated an engine surge condition just after takeoff. After about 1 second of the abnormally high engine operating condition, engine power dropped and an engine flameout occurred. Power to the rotor system was regained about 4 seconds later, but there was not sufficient altitude available for the pilot to recover.

The pilot later reported that before departure, he brought the helicopter into a stationary hover in the middle of the helideck and made a "left pedal turn into the wind and in a direction to avoid the flare boom." According to a monthly gas flaring and venting volume summary provided by the platform operator, the volume of methane vented on the day of the accident was the highest of the month and about 20 times the volume of the second highest day. The pilot was not aware before departing that methane gas was being vented. While a windsock is located on the platform to assist pilots in determining the prevailing wind direction, as recommended in industry guidance, the platform does not have a system visible to pilots indicating when gas is venting; such a system is particularly helpful since methane gas is colorless and odorless and pilots are not able to discern its presence. The following figure shows SS208H with its helideck and flare boom.

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[3] More information about this accident, NTSB case number CEN11LA252, is available at http://www.ntsb.gov/aviationquery/index.aspx.

[4] Additional preliminary information about this accident, NTSB case number CEN13FA491, is available at http://www.ntsb.gov/aviationquery/index.aspx.

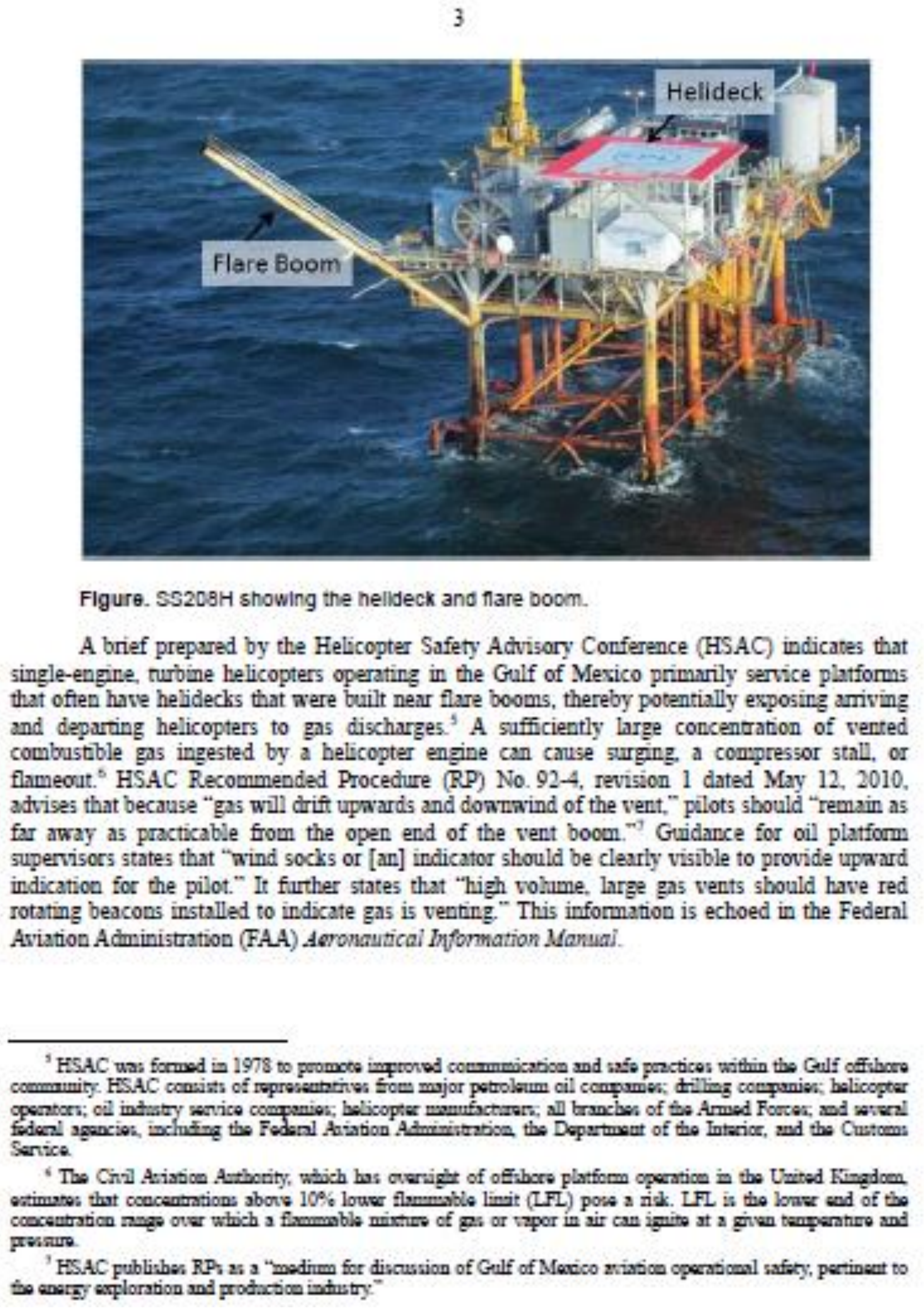

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Figure. SS208H showing the helideck and flare boom.

A brief prepared by the Helicopter Safety Advisory Conference (HSAC) indicates that single-engine, turbine helicopters operating in the Gulf of Mexico primarily service platforms that often have helidecks that were built near flare booms, thereby potentially exposing arriving and departing helicopters to gas discharges.[5] A sufficiently large concentration of vented combustible gas ingested by a helicopter engine can cause surging, a compressor stall, or flameout.[6] HSAC Recommended Procedure (RP) No. 92-4, revision 1 dated May 12, 2010, advises that because "gas will drift upwards and downwind of the vent," pilots should "remain as far away as practicable from the open end of the vent boom."[7] Guidance for oil platform supervisors states that "wind socks or [an] indicator should be clearly visible to provide upward indication for the pilot." It further states that "high volume, large gas vents should have red rotating beacons installed to indicate gas is venting." This information is echoed in the Federal Aviation Administration (FAA) *Aeronautical Information Manual*.

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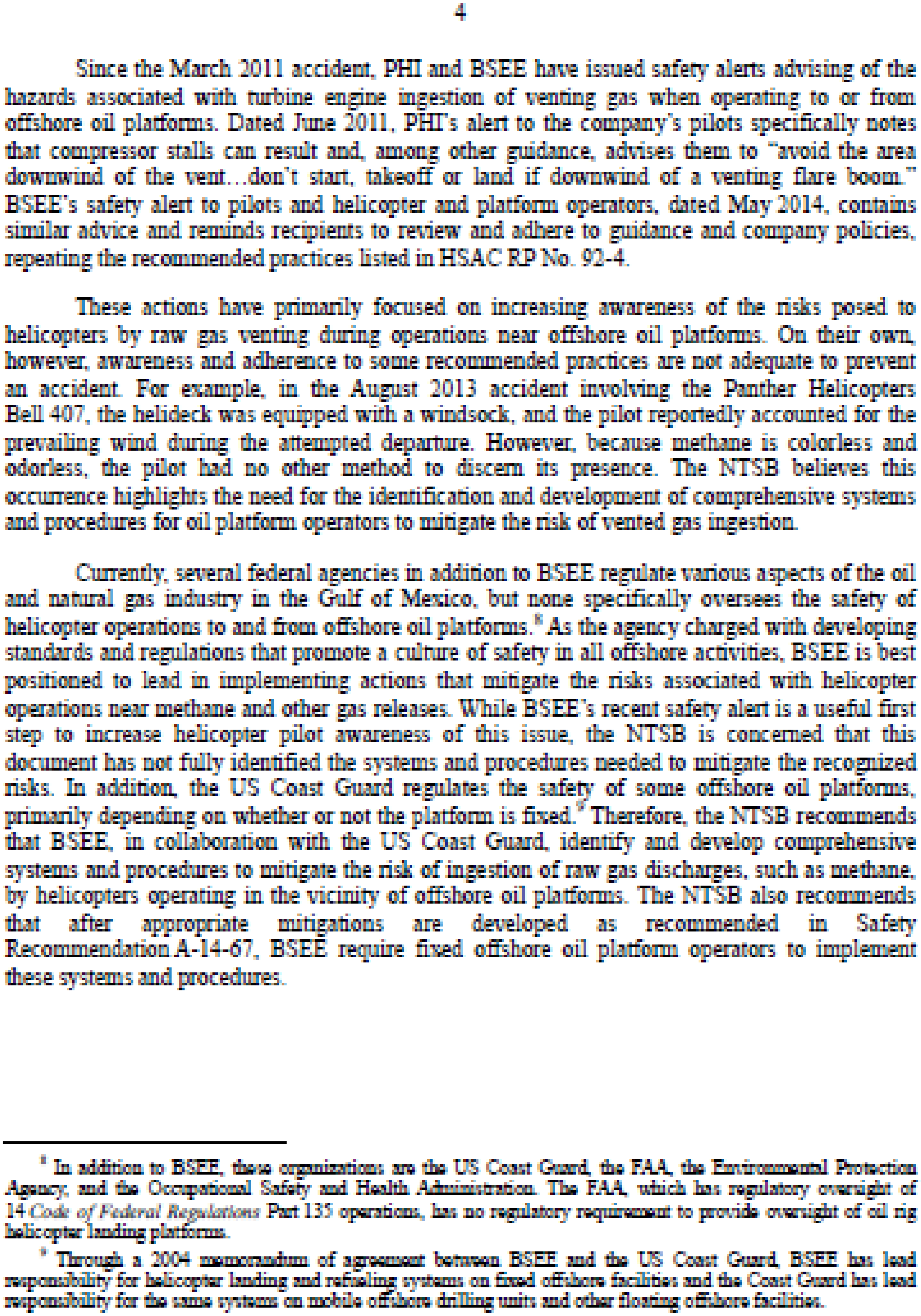
[5] HSAC was formed in 1978 to promote improved communication and safe practices within the Gulf offshore community. HSAC consists of representatives from major petroleum oil companies; drilling companies; helicopter operators; oil industry service companies; helicopter manufacturers; all branches of the Armed Forces; and several federal agencies, including the Federal Aviation Administration, the Department of the Interior, and the Customs Service.

[6] The Civil Aviation Authority, which has oversight of offshore platform operation in the United Kingdom, estimates that concentrations above 10% lower flammable limit (LFL) pose a risk. LFL is the lower end of the concentration range over which a flammable mixture of gas or vapor in air can ignite at a given temperature and pressure.

[7] HSAC publishes RPs as a "medium for discussion of Gulf of Mexico aviation operational safety, pertinent to the energy exploration and production industry."



Since the March 2011 accident, PHI and BSEE have issued safety alerts advising of the hazards associated with turbine engine ingestion of venting gas when operating to or from offshore oil platforms. Dated June 2011, PHI's alert to the company's pilots specifically notes that compressor stalls can result and, among other guidance, advises them to "avoid the area downwind of the vent…don't start, takeoff or land if downwind of a venting flare boom." BSEE's safety alert to pilots and helicopter and platform operators, dated May 2014, contains similar advice and reminds recipients to review and adhere to guidance and company policies, repeating the recommended practices listed in HSAC RP No. 92-4.

These actions have primarily focused on increasing awareness of the risks posed to helicopters by raw gas venting during operations near offshore oil platforms. On their own, however, awareness and adherence to some recommended practices are not adequate to prevent an accident. For example, in the August 2013 accident involving the Panther Helicopters Bell 407, the helideck was equipped with a windsock, and the pilot reportedly accounted for the prevailing wind during the attempted departure. However, because methane is colorless and odorless, the pilot had no other method to discern its presence. The NTSB believes this occurrence highlights the need for the identification and development of comprehensive systems and procedures for oil platform operators to mitigate the risk of vented gas ingestion.

Currently, several federal agencies in addition to BSEE regulate various aspects of the oil and natural gas industry in the Gulf of Mexico, but none specifically oversees the safety of helicopter operations to and from offshore oil platforms.[8] As the agency charged with developing standards and regulations that promote a culture of safety in all offshore activities, BSEE is best positioned to lead in implementing actions that mitigate the risks associated with helicopter operations near methane and other gas releases. While BSEE's recent safety alert is a useful first step to increase helicopter pilot awareness of this issue, the NTSB is concerned that this document has not fully identified the systems and procedures needed to mitigate the recognized risks. In addition, the US Coast Guard regulates the safety of some offshore oil platforms, primarily depending on whether or not the platform is fixed.[9] Therefore, the NTSB recommends that BSEE, in collaboration with the US Coast Guard, identify and develop comprehensive systems and procedures to mitigate the risk of ingestion of raw gas discharges, such as methane, by helicopters operating in the vicinity of offshore oil platforms. The NTSB also recommends that after appropriate mitigations are developed as recommended in Safety Recommendation A-14-67, BSEE require fixed offshore oil platform operators to implement these systems and procedures.

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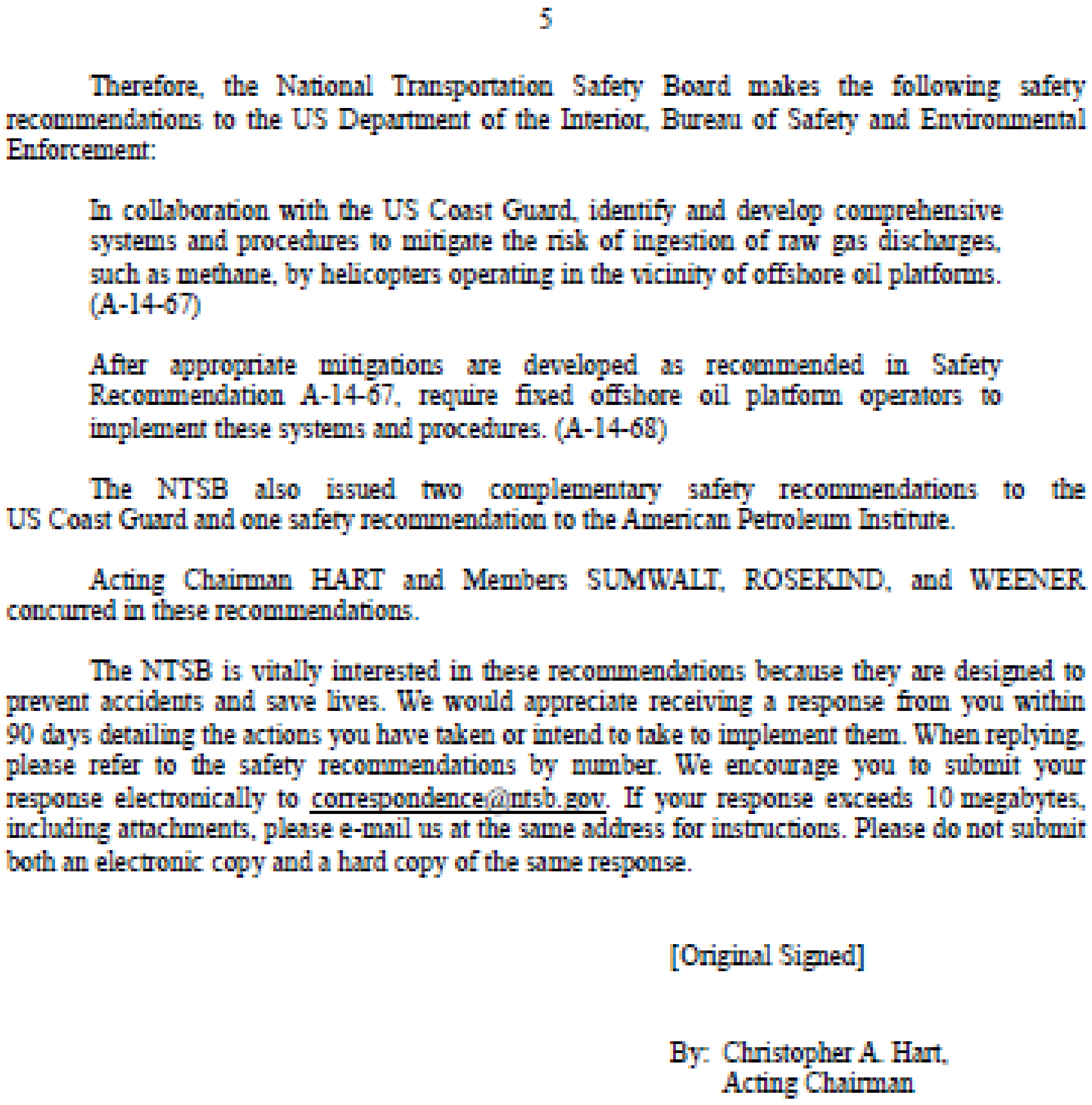
[8] In addition to BSEE, these organizations are the US Coast Guard, the FAA, the Environmental Protection Agency, and the Occupational Safety and Health Administration. The FAA, which has regulatory oversight of 14 *Code of Federal Regulations* Part 135 operations, has no regulatory requirement to provide oversight of oil rig helicopter landing platforms.

[9] Through a 2004 memorandum of agreement between BSEE and the US Coast Guard, BSEE has lead responsibility for helicopter landing and refueling systems on fixed offshore facilities and the Coast Guard has lead responsibility for the same systems on mobile offshore drilling units and other floating offshore facilities.



Therefore, the National Transportation Safety Board makes the following safety recommendations to the US Department of the Interior, Bureau of Safety and Environmental Enforcement:

> In collaboration with the US Coast Guard, identify and develop comprehensive systems and procedures to mitigate the risk of ingestion of raw gas discharges, such as methane, by helicopters operating in the vicinity of offshore oil platforms. (A-14-67)
>
> After appropriate mitigations are developed as recommended in Safety Recommendation A-14-67, require fixed offshore oil platform operators to implement these systems and procedures. (A-14-68)

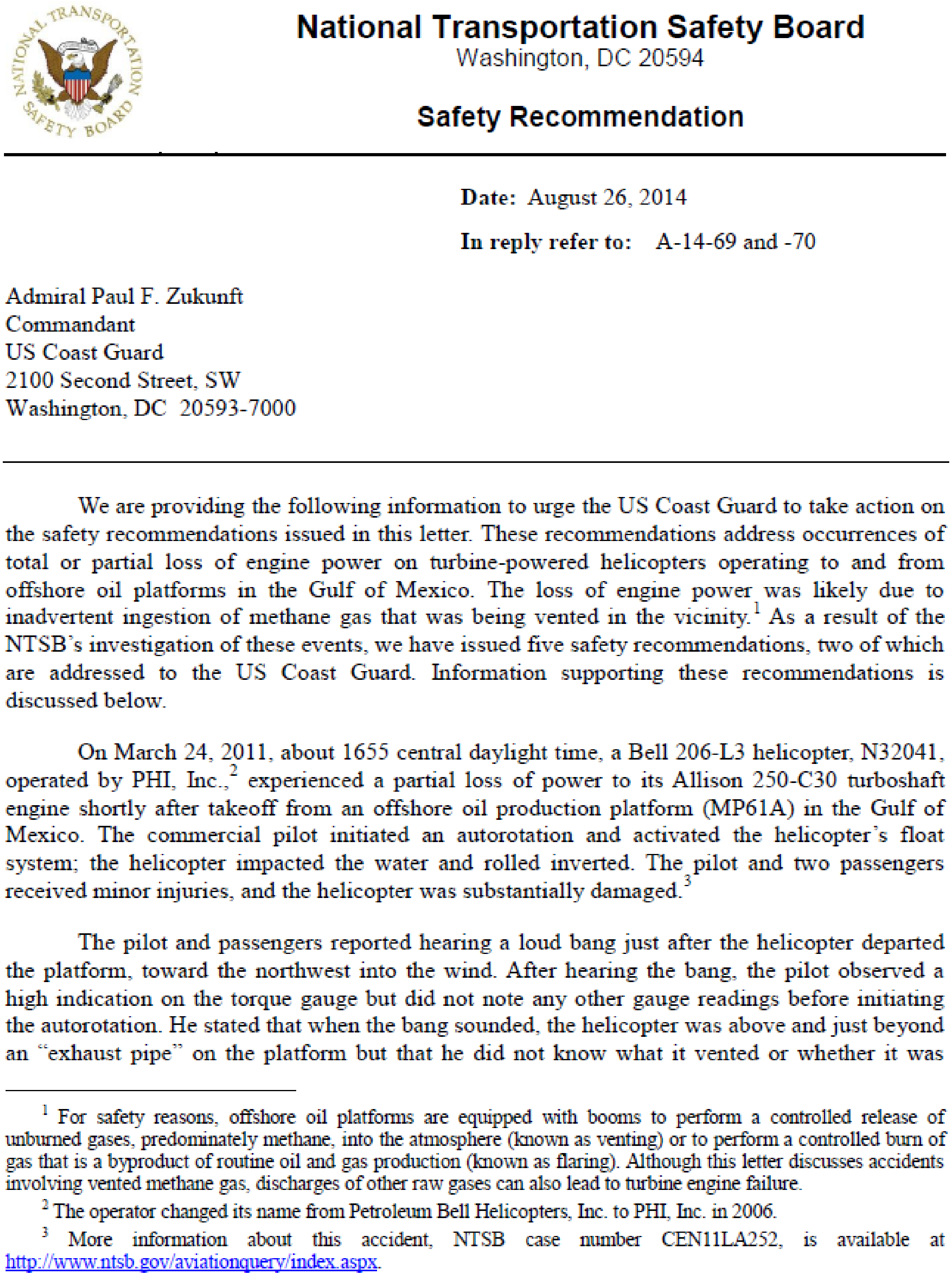
The NTSB also issued two complementary safety recommendations to the US Coast Guard and one safety recommendation to the American Petroleum Institute.

Acting Chairman HART and Members SUMWALT, ROSEKIND, and WEENER concurred in these recommendations.

The NTSB is vitally interested in these recommendations because they are designed to prevent accidents and save lives. We would appreciate receiving a response from you within 90 days detailing the actions you have taken or intend to take to implement them. When replying, please refer to the safety recommendations by number. We encourage you to submit your response electronically to correspondence@ntsb.gov. If your response exceeds 10 megabytes, including attachments, please e-mail us at the same address for instructions. Please do not submit both an electronic copy and a hard copy of the same response.

[Original Signed]

By: Christopher A. Hart,
Acting Chairman



National Transportation Safety Board
Washington, DC 20594

Safety Recommendation

Date: August 26, 2014

In reply refer to: A-14-69 and -70

Admiral Paul F. Zukunft
Commandant
US Coast Guard
2100 Second Street, SW
Washington, DC 20593-7000

We are providing the following information to urge the US Coast Guard to take action on the safety recommendations issued in this letter. These recommendations address occurrences of total or partial loss of engine power on turbine-powered helicopters operating to and from offshore oil platforms in the Gulf of Mexico. The loss of engine power was likely due to inadvertent ingestion of methane gas that was being vented in the vicinity.[1] As a result of the NTSB's investigation of these events, we have issued five safety recommendations, two of which are addressed to the US Coast Guard. Information supporting these recommendations is discussed below.

On March 24, 2011, about 1655 central daylight time, a Bell 206-L3 helicopter, N32041, operated by PHI, Inc.,[2] experienced a partial loss of power to its Allison 250-C30 turboshaft engine shortly after takeoff from an offshore oil production platform (MP61A) in the Gulf of Mexico. The commercial pilot initiated an autorotation and activated the helicopter's float system; the helicopter impacted the water and rolled inverted. The pilot and two passengers received minor injuries, and the helicopter was substantially damaged.[3]

The pilot and passengers reported hearing a loud bang just after the helicopter departed the platform, toward the northwest into the wind. After hearing the bang, the pilot observed a high indication on the torque gauge but did not note any other gauge readings before initiating the autorotation. He stated that when the bang sounded, the helicopter was above and just beyond an "exhaust pipe" on the platform but that he did not know what it vented or whether it was

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[2] The operator changed its name from Petroleum Bell Helicopters, Inc. to PHI, Inc. in 2006.

[3] More information about this accident, NTSB case number CEN11LA252, is available at http://www.ntsb.gov/aviationquery/index.aspx.

venting when he took off. The production foreman on the platform later reported that the flare boom was venting methane throughout the day, including at the time of the helicopter's departure. The platform was not equipped to provide any visual indication to pilots when gas was venting. Review of data from the helicopter's engine data monitoring system revealed a slight increase in the engine torque and turbine outlet temperature readings. The NTSB determined the probable cause of this accident was "the loss of engine power due to an engine compressor stall as a result of ingesting methane gas during takeoff."

On August 13, 2013, a Bell 407 helicopter, N53LP, operated by Panther Helicopters, Inc., experienced a total loss of power to its Rolls-Royce 250-C47B turboshaft engine shortly after takeoff from an offshore oil platform (SS208H) in the Gulf of Mexico. The pilot reported hearing a loud bang and attempted to increase the helicopter's forward airspeed but was unable. He then took mitigating actions once impact with the water was imminent. The pilot and two passengers sustained minor injuries, and the helicopter was substantially damaged.[4]

The NTSB's investigation of the 2013 accident is ongoing. Preliminary analysis of data from the helicopter's full authority digital electronic control system indicated an engine surge condition just after takeoff. After about 1 second of the abnormally high engine operating condition, engine power dropped and an engine flameout occurred. Power to the rotor system was regained about 4 seconds later, but there was not sufficient altitude available for the pilot to recover.

The pilot later reported that before departure, he brought the helicopter into a stationary hover in the middle of the helideck and made a "left pedal turn into the wind and in a direction to avoid the flare boom." According to a monthly gas flaring and venting volume summary provided by the platform operator, the volume of methane vented on the day of the accident was the highest of the month and about 20 times the volume of the second highest day. The pilot was not aware before departing that methane gas was being vented. While a wind sock is located on the platform to assist pilots in determining the prevailing wind direction, as recommended in industry guidance, the platform does not have a system visible to pilots indicating when gas is venting; such a system is particularly helpful since methane gas is colorless and odorless and pilots are not able to discern its presence. The following figure shows SS208H with its helideck and flare boom.

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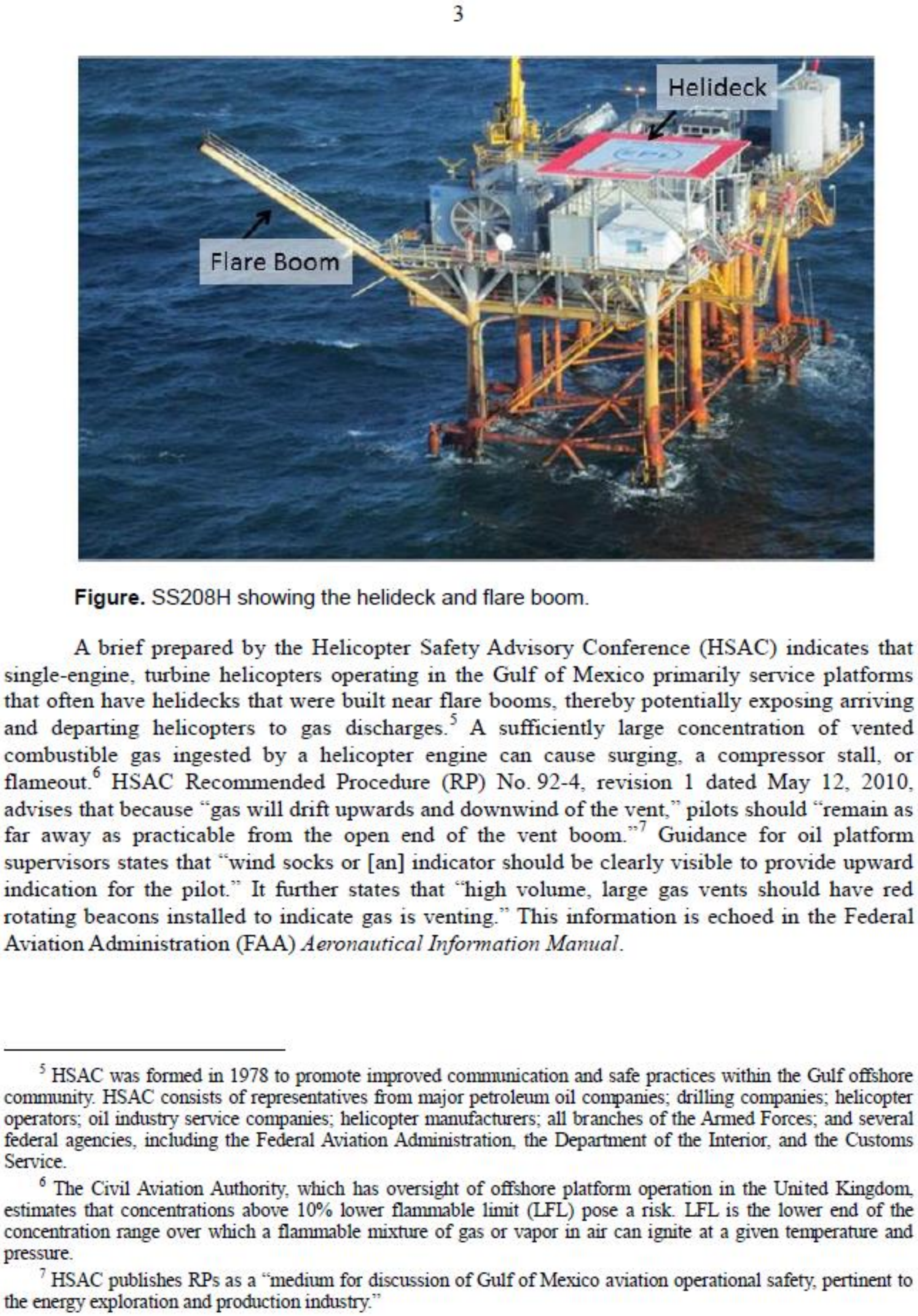

Figure. SS208H showing the helideck and flare boom.

A brief prepared by the Helicopter Safety Advisory Conference (HSAC) indicates that single-engine, turbine helicopters operating in the Gulf of Mexico primarily service platforms that often have helidecks that were built near flare booms, thereby potentially exposing arriving and departing helicopters to gas discharges.[5] A sufficiently large concentration of vented combustible gas ingested by a helicopter engine can cause surging, a compressor stall, or flameout.[6] HSAC Recommended Procedure (RP) No. 92-4, revision 1 dated May 12, 2010, advises that because "gas will drift upwards and downwind of the vent," pilots should "remain as far away as practicable from the open end of the vent boom."[7] Guidance for oil platform supervisors states that "wind socks or [an] indicator should be clearly visible to provide upward indication for the pilot." It further states that "high volume, large gas vents should have red rotating beacons installed to indicate gas is venting." This information is echoed in the Federal Aviation Administration (FAA) *Aeronautical Information Manual*.

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[6] The Civil Aviation Authority, which has oversight of offshore platform operation in the United Kingdom, estimates that concentrations above 10% lower flammable limit (LFL) pose a risk. LFL is the lower end of the concentration range over which a flammable mixture of gas or vapor in air can ignite at a given temperature and pressure.

[7] HSAC publishes RPs as a "medium for discussion of Gulf of Mexico aviation operational safety, pertinent to the energy exploration and production industry."

Since the March 2011 accident, PHI and the US Department of the Interior, Bureau of Safety and Environmental Enforcement (BSEE)[8] have issued safety alerts advising of the hazards associated with turbine engine ingestion of venting gas when operating to or from offshore oil platforms. Dated June 2011, PHI's alert to the company's pilots specifically notes that compressor stalls can result and, among other guidance, advises them to "avoid the area downwind of the vent…don't start, takeoff or land if downwind of a venting flare boom." BSEE's safety alert to pilots and helicopter and platform operators, dated May 2014, contains similar advice and reminds recipients to review and adhere to guidance and company policies, repeating the recommended practices listed in HSAC RP No. 92-4.

Corrective actions thus far have primarily focused on increasing awareness of the risks posed to helicopters by raw gas venting during operations near offshore oil platforms. On their own, however, awareness and adherence to some recommended practices are not adequate to prevent an accident. For example, in the August 2013 accident involving the Panther Helicopters Bell 407, the helideck was equipped with a wind sock, and the pilot reportedly accounted for the prevailing wind during the attempted departure. However, because methane is colorless and odorless, the pilot had no other method to discern its presence. The NTSB believes this occurrence highlights the need for the identification and development of comprehensive systems and procedures for oil platform operators to mitigate the risk of vented gas ingestion.

Currently, several federal agencies in addition to the US Coast Guard and BSEE, regulate various aspects of the oil and natural gas industry in the Gulf of Mexico, but none specifically oversees the safety of helicopter operations to and from offshore oil platforms.[9] As demonstrated by its May 2014 safety alert, BSEE has initiated work to increase awareness of the risks associated with helicopter operations near methane and other gas releases. The US Coast Guard should work with BSEE to identify and develop the needed mitigations for this issue and ensure that identified corrective actions are implemented for mobile offshore oil platforms. Therefore, the NTSB recommends that the US Coast Guard work with BSEE to identify and develop comprehensive systems and procedures to mitigate the risk of ingestion of raw gas discharges, such as methane, by helicopters operating in the vicinity of offshore oil platforms. The NTSB also recommends that, after appropriate mitigations are developed as recommended in Safety Recommendation A-14-69, the US Coast Guard require mobile offshore oil platform operators to implement these systems and procedures.

Therefore, the National Transportation Safety Board makes the following safety recommendations to the US Coast Guard:

> Work with the US Department of the Interior, Bureau of Safety and Environmental Enforcement to identify and develop comprehensive systems and procedures to mitigate the risk of ingestion of raw gas discharges, such as

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[8] Through a 2004 memorandum of agreement between the US Coast Guard and BSEE, BSEE has lead responsibility for helicopter landing and refueling systems on fixed offshore facilities and the Coast Guard has lead responsibility for the same systems on mobile offshore drilling units and other floating offshore facilities.

[9] In addition to the US Coast Guard and BSEE, these organizations are the FAA, the Environmental Protection Agency, and the Occupational Safety and Health Administration. The FAA, which has regulatory oversight of 14 *Code of Federal Regulations* Part 135 operations, has no regulatory requirement to provide oversight of oil rig helicopter landing platforms.

> methane, by helicopters operating in the vicinity of offshore oil platforms. (A-14-69)
>
> After appropriate mitigations are developed as recommended in Safety Recommendation A-14-69, require mobile offshore oil platform operators to implement these systems and procedures. (A-14-70)

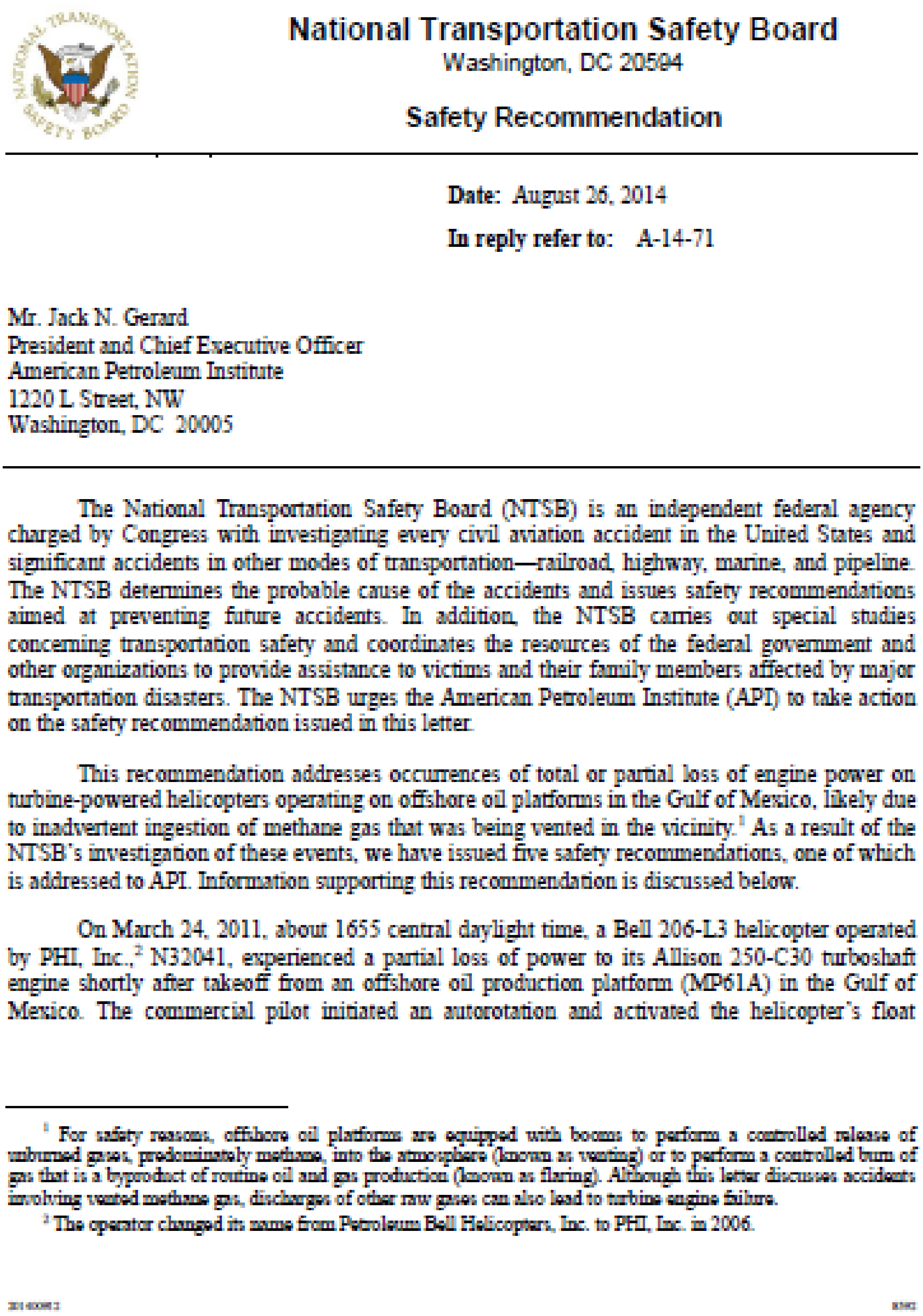
The NTSB also issued two complementary safety recommendations to the US Department of the Interior, Bureau of Safety and Environmental Enforcement and one safety recommendation to the American Petroleum Institute.

Acting Chairman HART and Members SUMWALT, ROSEKIND, and WEENER concurred in these recommendations.

The NTSB is vitally interested in these recommendations because they are designed to prevent accidents and save lives. We would appreciate receiving a response from you within 90 days detailing the actions you have taken or intend to take to implement them. When replying, please refer to the safety recommendations by number. We encourage you to submit your response electronically to correspondence@ntsb.gov.

[Original Signed]

By: Christopher A. Hart,
Acting Chairman



National Transportation Safety Board
Washington, DC 20594

Safety Recommendation

Date: August 26, 2014

In reply refer to: A-14-71

Mr. Jack N. Gerard
President and Chief Executive Officer
American Petroleum Institute
1220 L Street, NW
Washington, DC 20005

The National Transportation Safety Board (NTSB) is an independent federal agency charged by Congress with investigating every civil aviation accident in the United States and significant accidents in other modes of transportation—railroad, highway, marine, and pipeline. The NTSB determines the probable cause of the accidents and issues safety recommendations aimed at preventing future accidents. In addition, the NTSB carries out special studies concerning transportation safety and coordinates the resources of the federal government and other organizations to provide assistance to victims and their family members affected by major transportation disasters. The NTSB urges the American Petroleum Institute (API) to take action on the safety recommendation issued in this letter.

This recommendation addresses occurrences of total or partial loss of engine power on turbine-powered helicopters operating on offshore oil platforms in the Gulf of Mexico, likely due to inadvertent ingestion of methane gas that was being vented in the vicinity.[1] As a result of the NTSB's investigation of these events, we have issued five safety recommendations, one of which is addressed to API. Information supporting this recommendation is discussed below.

On March 24, 2011, about 1655 central daylight time, a Bell 206-L3 helicopter operated by PHI, Inc.,[2] N32041, experienced a partial loss of power to its Allison 250-C30 turboshaft engine shortly after takeoff from an offshore oil production platform (MP61A) in the Gulf of Mexico. The commercial pilot initiated an autorotation and activated the helicopter's float

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system; the helicopter impacted the water and rolled inverted. The pilot and two passengers received minor injuries, and the helicopter was substantially damaged.[3]

The pilot and passengers reported hearing a loud bang just after the helicopter departed the platform, toward the northwest into the wind. After hearing the bang, the pilot observed a high indication on the torque gauge but did not note any other gauge readings before initiating the autorotation. He stated that when the bang sounded, the helicopter was above and just beyond an "exhaust pipe" on the platform but that he did not know what it vented or whether it was venting when he took off. The production foreman on the platform later reported that the flare boom was venting methane gas throughout the day, including at the time of the helicopter's departure. The platform was not equipped to provide any visual indication to pilots when gas was venting. Review of data from the helicopter's engine data monitoring system revealed a slight increase in the engine torque and turbine outlet temperature readings. The NTSB determined the probable cause of this accident was "the loss of engine power due to an engine compressor stall as a result of ingesting methane gas during takeoff."

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The NTSB's investigation of the 2013 accident is ongoing. Preliminary analysis of data from the helicopter's full authority digital electronic control system indicated an engine surge condition just after takeoff. After about 1 second of the abnormally high engine operating condition, engine power dropped and an engine flameout occurred. Power to the rotor system was regained about 4 seconds later, but there was not sufficient altitude available for the pilot to recover.

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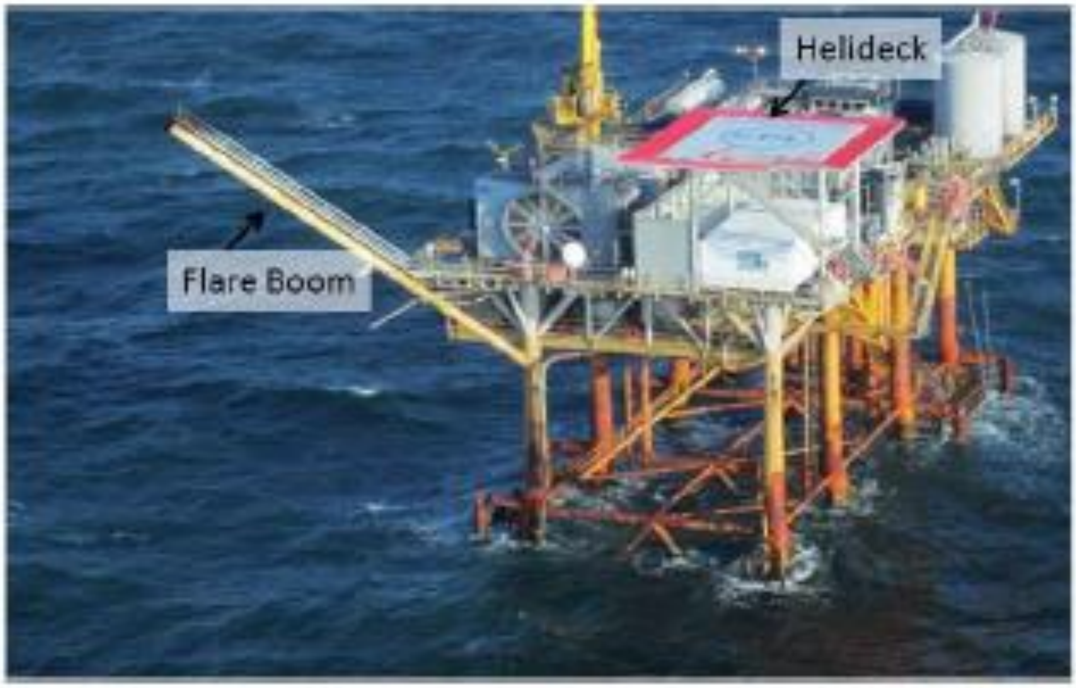

Figure. SS208H showing the helideck and flare boom.

A brief prepared by the Helicopter Safety Advisory Conference (HSAC) indicates that single-engine, turbine helicopters operating in the Gulf of Mexico primarily service platforms that often have helidecks that were built near flare booms, thereby potentially exposing arriving and departing helicopters to gas discharges.[5] A sufficiently large concentration of vented combustible gas ingested by a nearby helicopter turbine engine can cause surging, a compressor stall, or flameout.[6] Safety guidance materials produced by stakeholders in the Gulf of Mexico energy industry widely acknowledge this particular risk as a significant safety hazard.[7] However, API's guidance for planning and constructing heliports on offshore platforms (Recommended Practice 2L, *Recommended Practice for Planning, Designing, and Constructing Heliports for Fixed Offshore Platforms*, dated June 1, 1996) currently contains no mention of gas venting and its associated hazards.

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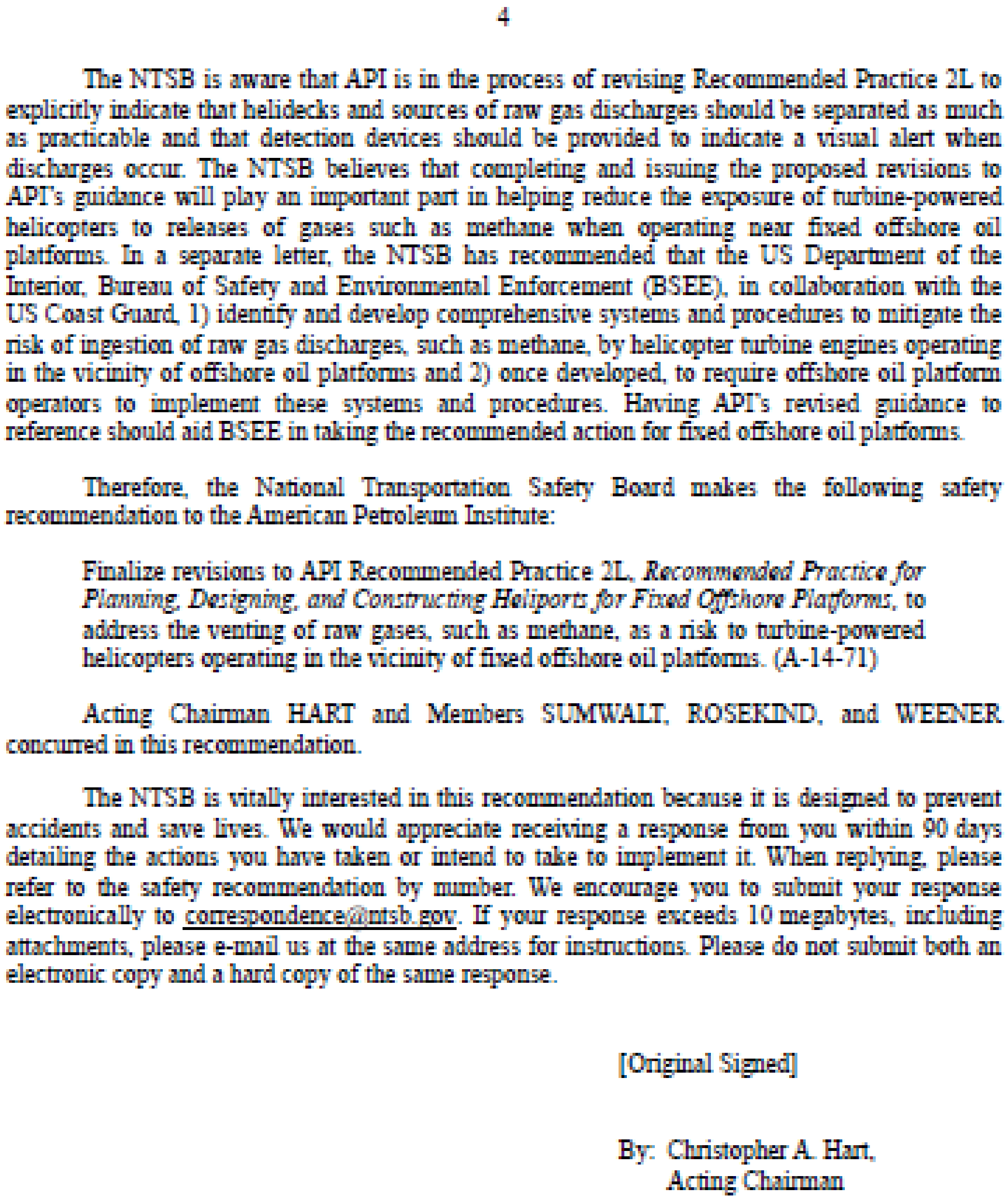
[7] For example, about 2 months after the March 2011 accident, PHI issued a safety alert to its pilots advising of the hazards associated with turbine engine ingestion of venting gas when operating to or from offshore oil platforms. The alert specifically noted that compressor stalls can result and, among other guidance, advised pilots to "avoid the area downwind of the vent…don't start, takeoff or land if downwind of a venting flare boom."



The NTSB is aware that API is in the process of revising Recommended Practice 2L to explicitly indicate that helidecks and sources of raw gas discharges should be separated as much as practicable and that detection devices should be provided to indicate a visual alert when discharges occur. The NTSB believes that completing and issuing the proposed revisions to API's guidance will play an important part in helping reduce the exposure of turbine-powered helicopters to releases of gases such as methane when operating near fixed offshore oil platforms. In a separate letter, the NTSB has recommended that the US Department of the Interior, Bureau of Safety and Environmental Enforcement (BSEE), in collaboration with the US Coast Guard, 1) identify and develop comprehensive systems and procedures to mitigate the risk of ingestion of raw gas discharges, such as methane, by helicopter turbine engines operating in the vicinity of offshore oil platforms and 2) once developed, to require offshore oil platform operators to implement these systems and procedures. Having API's revised guidance to reference should aid BSEE in taking the recommended action for fixed offshore oil platforms.

Therefore, the National Transportation Safety Board makes the following safety recommendation to the American Petroleum Institute:

> Finalize revisions to API Recommended Practice 2L, *Recommended Practice for Planning, Designing, and Constructing Heliports for Fixed Offshore Platforms*, to address the venting of raw gases, such as methane, as a risk to turbine-powered helicopters operating in the vicinity of fixed offshore oil platforms. (A-14-71)

Acting Chairman HART and Members SUMWALT, ROSEKIND, and WEENER concurred in this recommendation.

The NTSB is vitally interested in this recommendation because it is designed to prevent accidents and save lives. We would appreciate receiving a response from you within 90 days detailing the actions you have taken or intend to take to implement it. When replying, please refer to the safety recommendation by number. We encourage you to submit your response electronically to correspondence@ntsb.gov. If your response exceeds 10 megabytes, including attachments, please e-mail us at the same address for instructions. Please do not submit both an electronic copy and a hard copy of the same response.

[Original Signed]

By: Christopher A. Hart,
Acting Chairman

8. *Appendix D-Representative OCS Platforms*

9. *Appendix E – Helicopters Operating on the OCS*

Airframe Make	Airframe Model	Powerplant(s)	MGTOW (lbs)	Range (nm)	Capacity (pilot/pax)
Airbus/Eurocopter	AS350B3 Ecureuil/AStar	1 x Turbomeca Arriel 2B	4960	357	1/5
Airbus/Eurocopter	EC120B Colibri	1 x Turbomeca Arrius 2F	3780	383	2/11
Airbus/Eurocopter	EC130B4	1 x Turbomeca Arriel 2B	3036	329	1/4
AgustaWestland	AW119Ke Koala	1 x PW PT6B-37A	6383	535	1/7
Bell Helicopter Textron	204B Iroquois (Huey)	1 x Lycoming T53-11A	9,500	300	2/8
Bell Helicopter Textron	205B Iroquois (Huey)	1 x Lycoming T53-13B	10,500	300	2/13
Bell Helicopter Textron	206B/B-2 JetRanger	1 x Allison 250-C20B	3,000	379	1/4
Bell Helicopter Textron	206B-3 JetRanger	1 x Allison 250-C20J	3,000	379	1/4
Bell Helicopter Textron	206L LongRanger	1 x Allison 250-C20B	4,150	339	1/6
Bell Helicopter Textron	206L-1 LongRanger II	1 x Allison 250-C28B	4,150	374	1/6
Bell Helicopter Textron	206L-3 LongRanger III	1 x Allision 250-C30P	4,150	360	1/6
Bell Helicopter Textron	206L-4 LongRanger IV	1 x Allision 250-C30P	4,450	374	1/4
Bell Helicopter Textron	407	1 x Allision 250-C47B	2,722	324	1/6
Bell Helicopter Textron	214A Huey Plus	1 x Lycoming LTC4B-8D	15,000	255	2/14
MD/Hughes	MD500C	1 x Allision 250-C18B	2,550	325	1/4
MD/Hughes	MD500D/E	1 x Allison 250-C20B	3,000	258	1/4
MD/Boeing	MD500F/530F	1 x Allison 250-C30B	3,100	232	1/4
MD/Boeing	MD520N NOTAR	1 x Rolls-Royce 250-C20R	3,350	229	1/4
MD/Boeing	MD600N NOTAR	1 x Rolls-Royce 250-C47M	4,100	342	1/7
Robinson	R66	1 x Rolls-Royce RR300	2,700	325	1/4
Airbus/Eurocopter	AS355F2 Ecureuil 2/TwinStar	2 x Allision 250-C20F	5732	380	1/6
Airbus/Eurocopter	AS355N Ecureuil 2/Twin Star	2 x Turbomeca Arrius 1A	5732	380	1/6
Airbus/Eurocopter	AS355NP Ecureuil 2/Twin Star	2 x Turbomeca Arrius 1A	6173	380	1/6
Airbus/Eurocopter	AS365N3 Dauphin	2 x Turbomeca Arriel 2C	9480	447	2/11
Airbus/Eurocopter	EC135P1/P2	2 x PW206B	6250	343	1/7
Airbus/Eurocopter	EC135T1/T2	2 x Turbomeca Arrius 2B	6250	343	1/7
Airbus/Eurocopter	EC135P2+	2 x PW206B	6415	343	1/7
Airbus/Eurocopter	EC135T2+	2 x Turbomeca Arrius 2B	6415	343	1/7
Airbus/Eurocopter	EC135P3	2 x PW206B	6570	343	1/7
Airbus/Eurocopter	EC135T3	2 x Turbomeca Arrius 2B+	6570	343	1/7
Airbus/Eurocopter	EC145	2 x Turbomeca Arriel 1E	7093	461	1/9
Airbus/Eurocopter	EC145T2	2 x Turbomeca Arriel 2E	8047	356	1/9
Airbus/Eurocopter	EC155B1	2 x Turbomeca Arriel 2C	10847	463	2/13
Airbus/Eurocopter	EC225 Super Puma	2 x Turbomeca Makila 2A1	24,692	463	2/25
Agusta	A109A	2 x Allision 250-C20B	5732	350	1/7
Agusta	A109E	2 x PW206C	6283	528	1/7
AgustaWestland	AW109	2 x PW206C	6283	503	1/7
AgustaWestland	AW139	2 x PW PT6C-67C	14,110	675	2/15
Bell Helicopter Textron	212 Twin Huey	2 x PW PT6T-3B Twin-Pac	11,200	237	2/13
Bell Helicopter Textron	214ST	2 x GE CT7-2A	17,500	435	2/16
Bell Helicopter Textron	222B/U	2 x Lycoming LTS-101-750C	8,250	386	2/8
Bell Helicopter Textron	230	2 x Allison 250-C30G/2	8,400	378	2/8
Bell Helicopter Textron	412EP	2 x PW PT6T-3BE	11,900	402	2/13
Bell Helicopter Textron	427	2 x PW PW207D	6,550	394	1/7
Bell Helicopter Textron	429 GlobalRanger	2 x PW PW207D1	7,000	390	1/7
Bell Helicopter Textron	430	2 x Rolls-Royce 250-C40B	9,300	324	2/8
Eurocopter/Kawasaki	MBB/BK-117B-2	2 x Lycoming LTS-101-750B-1	7,385	336	1/9
MBB	Bo105CB	2 x Allison 250-C20B	5,511	310	1/7
Sikorsky	S-76A	2 x Allison 250-C30S	10,500	380	2/12
Sikorsky	S-76A+/A++	2 x Turbomeca Arriel 1S1	10,500		2/12
Sikorsky	S-76B	2 x PW PT6B-36A	11,700		2/12
Sikorsky	S-76C	2 x Turbomeca Arriel 2S	11,700		2/12
Sikorsky	S-76C+	2 x Turbomeca Arriel 2S1	11,700	439	2/12
Sikorsky	S-76C++	2 x Turbomeca Arriel 2S2	11,700	411	2/12
Sikorsky	S-76D	2 x PW210S	11,700		2/12
Sikorsky	S-92A Helibus	2 x GE CT7-8A	15,900	726	2/19

10. *Appendix F-Preliminary Engineering Analysis Report-(attached as separate document)*