EnDyna Peer Review Comments on the BSEE / PricewaterhouseCoopers (PwC) study entitled, *"Study on Effects of Combustible Gas on Helicopter Operations"*

Peer Reviewers Selected by the EnDyna Team

1.	NAME:	**Robert Williams**
	AFFILIATION:	Williams Aviation Resources
	EXPERTISE:	Robert Williams has 48 years of increasing levels of hands-on experience in worldwide aviation management, operations, safety, training, and technical fields. He recently held a leadership position in the Helicopter Safety Advisory Committee, a leading offshore oil and gas helicopter safety organization. He is experienced with offshore oil and gas helicopter operations, development of manned helipads and unmanned temporary helipads, specifications for and coordinated installation of fuel systems, and helicopter design specifications. He developed and published Aviation Operations Guidelines Supplement for Offshore Helicopter/Float Plane Operations and the Transportation Section of the Exxon USA Safety Manual (1990-1997). He is a Professional Aviator, Helicopter Pilot with offshore oil and gas experience.

2.	NAME:	**Edward J. Coleman**
	AFFILIATION:	Independent Aviation Consultant
	EXPERTISE:	Edward Coleman is a professional pilot and safety manager with experience in international operations, safety program management, analyzing and managing risk, accident investigation, platform instruction and writing/interpreting technical publications. He has experience in training and helicopters serving the off shore oil industry, and review of technical specifications for helideck design and fueling systems. Past experience includes Aviation Advisor, BP America (2012-2015), a position in which he monitored and maintained company standards to include interpretations of standards for aviation operations, and developed Oil and Gas Producers technical publications. He was a member of the company Mishap Response Team, trained in the use of the FEMA Incident Command System, with emphasis on Safety Management Systems. Mr. Coleman lead award winning safety programs at all levels from small operations of a few dozen aircraft to large organizations of over 10,000 people spanning multiple continents, and was an Adjunct Professor (2004-2014) teaching Aviation Safety, Emergency Management and Aviation Management.

3.	NAME:	**Gene Munson**
	AFFILIATION:	Independent Test and Evaluation Consultant
	EXPERTISE:	Gene Munson has 45 years of experience in flight, laboratory, test, flight safety, instrumentation, and flight analysis, with 20 years dedicated to engineering management of systems development labs and engineering flight test. He provided engineering support in the areas of test planning, instrumentation, and rotorcraft technical data research for BLR Aerospace, and provided flight test planning and conducted test operations, including test matrix for flight envelope validation for the MH-60M 160th SOAR. For Boeing Rotorcraft, Mr. Munson was Manager, Flight Test Instrumentation, Flight Data Analysis and Telemetry Ground Station Groups

	(1994-2005). He was responsible for various contracted research programs supporting the U.S. Army, U.S. Navy, and NASA rotorcraft engineering research programs. He managed technical and programmatic facets of research, development, and test programs.

Overall comments

All three reviewers commented that the Study on Effects of Combustible Gas on Helicopter Operations report was written objectively and transparently. One reviewer commented that the analysis, conclusions, and recommendations were supported by the data presented. Another reviewer mentioned that the report had a significant amount of good data. One reviewer generally supported that the PwC Team made a good effort with the inputs from various sources plus the documentation obtained from research. A reviewer commented that the PwC Team was able to interpret the various documents and expert inputs to create a cohesive document that demonstrated cause and effect from the cold flaring on the platforms that resulted in aircraft engine failure with forced ditching of the aircraft with severe damage, loss, and injuries. This reviewer also stated that the engine data was excellent in its presentation and explanation and noted that most of that data was focused on the 650 SHP engines found in the single engine helicopters used for personnel and cargo transit work to various platforms and generally for short duration flights with a number of takeoffs and landings.

The three reviewers generally agreed that all readily available relevant studies or sources of information/data were consulted by the PwC Team. One reviewer commented that significant research will be necessary for determining the types of instrumentation that will be effective to address the uncertainties that were identified by the PwC Team with respect to methane gas density and quantity mapping during exhausting as a cold gas.

Two reviewers commented that the methodology was appropriate. One reviewer added that the use of current regulations, recent studies, accident data, and mathematical simulation were important parts of the study. This reviewer also stated that the variables, assumptions, and relevant dimensions were clearly identified and characterized. One reviewer stated that the variables, assumptions, and relevant dimensions were excellent for the helicopter engine engineering analysis, using engine operational data tables, operational parameter maps, and theory of operation equations. One reviewer noted that raw engine operational theory was explored along with definition of engine configurations as well as mechanization of fuel control types. This reviewer also commented on Appendix F from The Texas A&M Propulsion Laboratory and stated that the data collection was excellent for this engine documentation.

With respect to additional data analysis, one reviewer commented that a significant number of computational fluid dynamics (CFD) test cases could be run using the methane density and atmospheric data to generate a large number of cases. In addition, this reviewer commented that the rotor downwash models could be integrated into the total model to visualize gas dispersion and density during approach and landing and when hovering over the helideck doing the power check and then during transition to forward flight for departure. With respect to data collection, the reviewer acknowledged that the platform data and the hot and cold methane gas issues were not as exact, compared to the other data in this same study, because this reviewer noted it would take significant instrumentation to determine the methane gas flow signature in its cold state plus the hot flared dispersion. The reviewer stated that this would produce many test cases of wind velocity and direction plus temperature and dew point variations.

Two reviewers commented that the conclusions were logical and appropriate. One reviewer more specifically stated that it was unlikely that every offshore facility would have a CFD gas dispersion model, because CFDs are very expensive and are normally only conducted for new build facilities or facilities with airstream contamination issues. In addition, the reviewer could not identify where the assumption was made for the report that each facility would have a CFD completed, and questioned the validity of that assumption.

Study on Effects of Combustible Gas on Helicopter Operations Charge Questions and Answers

1. In the Executive Summary of the Study on Effects of Combustible Gas on Helicopter Operations Report, are the goals and accomplishments of the Task clearly stated? Please explain your answers.

Two reviewers commented that the goals and accomplishments of the study were clearly stated. One reviewer commented more specifically that the goals were clearly stated regarding the mitigation of risk for helicopter operations on helidecks located on drilling platforms where methane gas is exhausted in its unburned state from cold flaring and also where hot flaring occurs to burn off methane and its constituent accompanying gaseous elements.

This reviewer also noted the events that can occur with compressor stall during takeoff from offshore drilling platforms with resultant partial or total engine failure with the pilot taking action for forced ditching with autorotation and deploying the emergency float kit. The reviewer stated that two major goals should be required. This reviewer stated that the first goal should be total documentation of engine characteristics positively defined through possible testing to verify the exact percentage of free air versus percentage of cold methane that will cause compressor stall in various helicopter turbine engines. The reviewer suggested that testing should cover the representative engines used in various helicopters in the GOM. This reviewer stated that the second goal should be related to concern about where cold and burning gas is occurring on the platform and actions that will be needed to mitigate the helicopters from entering a gas exhaust cloud during the critical part of an approach to land on the helideck or during takeoff from hover to transition to forward flight in proximity to the helideck.

2. Is the methodology used for the Study on Effects of Combustible Gas on Helicopter Operations reasonable to adequately address specific task areas? Please describe the strengths and/or weaknesses of the analytical methods. Please answer the following as:

- ***Are variables, assumptions and relevant dimensions clearly identified and characterized?***

- ***Are data collection methods and inputs presented in a transparent manner?***
- ***Was the data analysis appropriate and/or should other techniques or analytic platforms have been considered?***

Please explain your answers and provide any specific examples as needed.

Two reviewers commented that the methodology was appropriate. One of those reviewers added that the use of current regulations, recent studies, accident data, and mathematical simulation were important parts of the study. One reviewer did not comment specifically on the overall methodology, but instead provided more detailed comments.

<u>Variables, Assumptions, and Relevant Dimensions</u>

One reviewer stated that the variables, assumptions, and relevant dimensions for the study were clearly identified and characterized. Another reviewer noted that the variables, assumptions, and operational dimensions were identified based on the necessary understanding of drilling platform operations where various locations are used for exhausting cold methane gas and also hot flaring excess methane. This reviewer added that this effort may require standardized platform construction and proximity of these flaring outputs in proximity to the helideck, information about prevailing winds for the location, and shutdown of those flaring operations when helicopters bring personnel and supplies or are conducting flight operations. Other considerations noted by this reviewer were controlling flaring during flight operations by platform construction methods and sensor placement for gas detection and atmospheric conditions with real-time data transmitted to the flight crew. This reviewer also stated that the variables, assumptions, and relevant dimensions were excellent for the helicopter engine engineering analysis, using engine operational data tables, operational parameter maps, and theory of operation equations. The reviewer noted that raw engine operational theory was explored along with definition of engine configurations as well as mechanization of fuel control types.

<u>Data Collection Methods</u>

Two reviewers commented that the data collection methods were good, but also provided some additional comments about the data collection. One of those reviewers stated that the data collection methods were presented well; however, this reviewer commented that the math could be a bit daunting and the reviewer believed that it may not be possible for the average reader to easily follow along with the math equations and conclusions. Another one of those reviewers commented more specifically that the data collection was good on offshore drilling platforms and their varied configurations and other variables, such as environmental considerations due to location in the GOM. This reviewer acknowledged that the platform data and the hot and cold methane gas issues were not as exact because this reviewer noted it would take significant instrumentation to determine the methane gas flow signature in its cold state plus the hot flared dispersion. The reviewer stated that this would produce many test cases of wind velocity and direction plus temperature and dew point variations.

One reviewer commented on Appendix F from The Texas A&M Propulsion Laboratory and stated that the data collection was excellent for this engine documentation. This reviewer further commented that the data was excellent for the engine information as it was classic mathematical techniques generally used for turboshaft engines used in helicopters. The reviewer noted that the power and efficiency and limits plots generally appear in original equipment manufacturer (OEM) engine deck data that is used in engine airframe compatibility and performance testing by the helicopter OEM. Although this reviewer acknowledged that the detailed engine data is not released per engine OEM confidentiality, this reviewer noted that the helicopter's flight manual will have performance charts derived with drivetrain and inlet losses factored in.

Data Analysis

With respect to additional data analysis, one reviewer commented that a significant number of computational fluid dynamics (CFD) test cases could be run using the methane density and atmospheric data to generate a large number of cases. In addition, this reviewer commented that the rotor downwash models could be integrated into the total model to visualize gas dispersion and density during approach and landing and when hovering over the helideck doing the power check and then during transition to forward flight for departure.

3. For the Study on Effects of Combustible Gas on Helicopter Operations, are any scientific uncertainties clearly identified and adequately characterized? For the technical conclusions drawn by the report, are the potential implications of the uncertainties clearly identified? Please explain your answers.

Two reviewers commented that the uncertainties were clearly identified and adequately characterized. One of those reviewers added that the report had a significant amount of good data. Another one of those reviewers mentioned that the report recommended additional studies to clear up the uncertainties.

One reviewer provided detailed observations about the uncertainties for the study. With respect to the uncertainties that were identified in methane gas density and quantity mapping during exhausting as a cold gas, this reviewer commented that significant research will be necessary for determining the types of instrumentation used that will be effective. The reviewer mentioned that Infrared was effective in clear air; however, atmospheric perturbations may mask the real exhaust signature of the methane gas. The reviewer noted that LIDAR (extremely high frequency radar) might be able to discriminate between atmospheric elements and methane gas, but acknowledged that this idea was just a guess and may require some extensive algorithm research.

This reviewer also commented on the uncertainties associated with lack of testing for engine stalling. The reviewer acknowledged that engine compressor stall or surge was fairly well defined as occurring with 3% or greater of atmosphere of methane gas from the aspect that it may or may not be burned in the compressor (as most inert gases would also not be burned) and would cause an instantaneous compressor stall or surge and engine shutdown. The reviewer noted that studies at the Texas A&M Engine Test Lab have been accomplished, but no specific testing reported. This reviewer stated that, to the reviewer's knowledge, no instrumented engines have been installed in a test fixture similar to the water ingestion test fixture and subjected to inert or combustible gas ingestion engine reaction to various mixtures with documented results.

This reviewer had anticipated that other possible studies on gas turbine engines for compressor stall could be conducted at NASA Lewis Research Center, but the reviewer did not find any NASA papers online describing the stall surge phenomena of either combustible or non-combustible studies of gas turbine or turboshaft engines at that facility. The reviewer had contacted all major helicopter turboshaft engine OEMs on the gas ingestion issue and found there was little information divulged by those engine OEMs.

The reviewer believed that no studies were found, because if the engine OEMs were to accomplish testing with company funds they would likely hold those studies and possible testing proprietary. The reviewer commented that at various times over the years, the reviewer had visited Rolls Royce, Turbomeca, Pratt and Whitney, and Honeywell Turboshaft test facilities and had observed that the development and qualification testing was accomplished in test cells in a building, and the water ingestion test stand was an exterior test cell in case of engine catastrophic failure. This reviewer had never observed any test cell hardware that suggested any stall or surge testing was accomplished with inert or combustible gases.

4. For the Study on Effects of Combustible Gas on Helicopter Operations, are the conclusions logical and appropriate based on the results and relevant data? Can the conclusions be easily and accurately interpreted? Please explain your answers.

Two reviewers commented that the conclusions were logical and appropriate. One reviewer provided specific comments about the conclusions, as summarized below.

Of the reviewers that commented that the conclusions were logical and appropriate, one reviewer explained this related especially to the drilling platform configurations that need to be optimized and standardized for safe operations. This reviewer stated that this standardization would be consistent with API and international standards on heliport location on the platform along with flaring and exhausting locations that would least impinge upon flight operations. The reviewer also commented that there were many ancillary issues that need to be resolved, including providing communications from the platform to incoming and outgoing aircraft during all flight operations, training for the platform personnel in safety and airborne radio communications, and atmospheric data and flaring data through real-time transmission to incoming or outgoing flight operations.

This reviewer also mentioned that the air turbine engine data was significant in its scientific nature, but it could be a bit difficult to understand for those unfamiliar with engine operational equations. The reviewer commented that, for the most part, the explanation was clear for the engine operations, configuration variations, as well as the focus on the engine size where the accidents occurred and the susceptibility of the engine size ranges to compressor stall with either nominal engine inlet temperature changes or cold gas ingestion.

One reviewer provided specific comments about the conclusions, as listed below:

- Page 43: This reviewer commented that the third paragraph mentioned “Until a CFD gas dispersion model is constructed for each offshore oil & gas facility in accordance with the recommendation in Subtask C.4.5.3(a) . . .” The reviewer stated that it was unlikely that every offshore facility would have a CFD, because CFDs are very expensive and are normally only conducted for new build facilities or facilities with airstream contamination issues. The reviewer could not identify where the assumption was made that each facility would have a CFD completed, and questioned the validity of that assumption. In addition, the reviewer mentioned the information about helicopter traffic coordination centers (HTCCs) from later in the same paragraph, and commented that very few facilities have HTCCs and only manned facilities could possibly have such facilities or weather systems.
- Page 44: This reviewer noted that the end of the first paragraph mentioned API RP 2L-1, which the reviewer observed did not currently exist because it was currently only in a draft form. The reviewer suggested that HSAC RP 2016-01 could be mentioned instead as a reference with similar content.[1]

5. For the Study on Effects of Combustible Gas on Helicopter Operations, are there any additional studies or sources of information/data that should have been consulted by the PwC Team Task authors?

Two reviewers commented that there were no additional studies or sources of information/data that should have been consulted by the PwC Team. Another reviewer stated that there were no big data

[1] HSAC RP 2016-01: Helideck Design Guideline (New Builds) was published in January 2016, after completion of the PwC Study in October 2015.

sources that could be helpful other than NASA's research produced at Lewis Field and U.S. Army Test Reports on engine testing that were not available either because of OEM sensitivity or still being under some classification. The reviewer mentioned that generally for every helicopter developed and qualified for the U.S. Army ADS-1B (Aeronautical Design Standards), there will be a family of engine surveys accomplished for each aircraft or engine upgrade to a specific helicopter. The reviewer provided a list of most important of those surveys and demonstrations: engine airframe compatibility, propulsion system vibration, propulsion system temperature, engine air induction system, engine exhaust, fuel system, and many other subsystem items. The reviewer commented that many of these U.S. Army engines have civilian equivalents so valuable data can be found if the U.S. Army documents were in the public domain. The reviewer also commented that the U.S. Navy uses some similar test requirements documents to execute their engine airframe qualification testing.

6. For the Study on Effects of Combustible Gas on Helicopter Operations, can BSEE be confident in the analysis, conclusions, and recommendations drawn from PwC Team's product? Are there any additional conclusions that could be drawn? Are there any apparent weaknesses or gaps in the PwC Team's research and analysis, including findings and recommendations? Please explain your answers.

One reviewer commented that the analysis, conclusions, and recommendations were supported by the data presented; however, this reviewer suggested that BSEE consider CAP 437 as summarized below. Another reviewer simply mentioned that the Report had a significant amount of good data.

Another reviewer generally supported that the PwC Team made a good effort with the inputs from various sources plus the documentation obtained from research. This reviewer commented that the PwC Team was able to interpret the various documents and expert inputs to create a cohesive document that demonstrated cause and effect from the cold flaring on the platforms that resulted in aircraft engine failure with forced ditching of the aircraft with severe damage, loss, and injuries. This reviewer stated that the study demonstrated a continuum of defining shortcomings of platform configuration plus operational issues where information was not relayed to the flight crew, generally a single pilot operation with a high task load. The reviewer commented that the study addressed corrective measures of interpreting the cold and hot flare phenomena with instrumentation and also providing information to the flight crew on path of the hot and cold flare, especially the methane gas, for takeoff and also approach and land.

This reviewer stated that the engine data was excellent in its presentation and explanation and noted that most of that data was focused on the 650 SHP engines found in the single engine helicopters used for personnel and cargo transit work to various platforms and generally for short duration flights with a number of takeoffs and landings. The reviewer noted that the only medium twin helicopter with a single engine compressor stall and flameout had larger and higher horsepower engines, but was still subject to methane gas ingestion with a compressor stall. The reviewer believed that this section quantified many engine operating norms and brought to light anomalies that upset normal engine operating parameters.

One reviewer, as noted above, believed that BSEE could consider making CAP 437 the standard for offshore helicopter landing areas. The reviewer stated that the USCG, as of September 3, 2015, had formally accepted CAP 437 as the USCG standard for offshore helicopter landing areas applicable to Mobile Offshore Drilling Units (MODUs) and Floating OCS facilities. This reviewer believed that BSEE should follow the USCG and use the standards in CAP 437 until there are more comprehensive standards available in the U.S. The reviewer argued that this would also standardize the requirements for OCS helidecks in the U.S. regardless of who has jurisdiction for them.

One reviewer commented that the study was quite complex and discussed effects of flared and non-flared methane gas and its effect especially on the smaller single gas turbine engine helicopters. This reviewer stated that the study provided insight into the issues of barometric and gas sampling instrumentation to indicate wind direction and velocity, barometric, dew point, and methane gas/air ratios that can inhibit gas turbine engine performance and, after a critical ratio, can cause compressor stall and engine shutdown. The reviewer commented that the report explained these issues moderately well, but the reviewer believed that these conditions were somewhat difficult to explain without being exposed to the engineering aspects of engine development test and qualification.

7. Was the Study on Effects of Combustible Gas on Helicopter Operations written objectively and transparently? Please explain any ways in which the report could be improved with regard to clarity and ease of use.

All three reviewers commented that the report was written objectively and transparently. One reviewer explained that the report used the facts and data from outside personnel and reference documents without editorializing or the writer's own views being projected into the documentation. This reviewer also commented that the documentation had a logical flow for the subjects, issues, and possible remedies on the platforms as well as aircraft and various preventive measures to mitigate many safety issues.