SUMMARY OF DOCUMENTS THAT ADDRESS POTENTIAL FLIGHT SAFETY IMPACT OF EXPOSURE TO CONFIRMED/SUSPECTED OIL-CONTAMINATED VENTILATION AIR ON COMMERCIAL AND MILITARY AIRCRAFT, AND SUPPORTING DOCUMENTATION

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1. **CIAIAC (2014) "Interim Statement A-008/2013: Accident occurred to aircraft Boeing B-757-300, registration D-ABOC, operated by Condor Flugdienst GmbH, at Gran Canaria airport on 22 March 2013."** (The Spanish aircraft accident investigation authority published an interim report into its investigation into a report on inflight exposure to fumes on a B757 during a flight from Hamburg, Germany to Gran Canaria, Spain. The crew had reported air supply system sourced fumes in the flight deck and cabin. The first officer had felt dizzy and donned his oxygen mask. After landing, the pilots and cabin crew had been instructed to stay onboard during system troubleshooting to identify the potential source of the fumes. When fumes again filled the cabin, two of the cabin crew developed symptoms serious enough to be administered oxygen and transferred to hospital, and they were later diagnosed with neurotoxin poisoning. Their symptoms were consistent with exposure to oil fumes, but the maintenance technicians only identified deicing fluid contamination in the APU on their aircraft, not oil. Four days later, during a positioning flight, intense fumes again filled the flight deck and cabin. The pilots donned oxygen and the purser and first officer both reported numb tongues and irritated throats. The cause of the second incident was not identified. The Spanish authority classified the first incident as an accident and is continuing to investigate, in partnership with the German BFU.)

2. **ASHRAE (2013) "Air Quality Within Commercial Aircraft: Standard 161-2013" American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, GA** (Comprehensive aircraft air quality standard requires continuous bleed air monitoring with flight deck indication for smoke/fume-related contaminants, and recommends control measures to prevent bleed air contamination, and consideration of bleed air cleaning technologies.)

3. **AAIB (2013) Bulletin no. 3/2013, Boeing 757-28A, G-FCLA (EW/G2012/10/09), UK Air Accidents Investigation Branch, UK Department for Transport** (UK accident investigator report describes an aircraft that filled with oil fumes/smoke from a faulty APU after arrival, requiring the cabin crew to evacuate the aircraft. The next day, oil fumes contaminated the flight deck air supply on takeoff, but the pilots did not don their oxygen masks until they had symptoms at the top of climb, at which time they initiated an emergency diversion.)

4. **IFALPA (2013) International Federation of Air Line Pilots' Associations Safety Bulletin 13SAB006** (International pilot body acknowledges the flight safety consequences when pilots experience acute symptoms inflight as a result of exposure to oil-contaminated supply air. The briefing leaflet calls for relevant training and education for crewmembers, including an explicit recommendation that pilots don oxygen masks if they suspect air supply contamination, even in the absence of visible smoke or haze.)

5. **ASHRAE (2012) Guideline 28-2012: Air Quality within Commercial Aircraft** (Engineering association guideline document recommends continuously monitoring for bleed air contaminants in the ventilation supply air, with a separate sensor on each potential source of contaminants to enable prompt identification and isolation. Guideline 28 also recommends that airlines train flight deck and cabin crewmembers to recognize and respond to fumes, and train maintenance workers to properly investigate and maintain relevant systems.)

6. **BFU (2012) News clip and excerpt from report published in March 2012 by German aviation accident investigator, BFU** (German investigative report describes a commercial airline flight on Nov. 18, 2011 during which the engine oil contaminated the aircraft supply air and the first officer was partially incapacitated. The first officer's blood tested positive for one form of tricresyl phosphate (TCP), a neurotoxic additive in aviation engine oil.)

7. **Michaelis, S (2011) Health and flight safety implications from exposure to contaminated air in aircraft"** (PhD thesis examines the consequences of exposure to contaminated air in flight, including the flight safety implications. Summary provided in: Michaelis, S (2011) "Contaminated aircraft cabin air" J Biol Phys Chem, 11(4): 132-145.)

8. **Murawski (2011) "Case study: analysis of reported contaminated air events at one major US airline in 2009-10"** (The author reviewed documentation for 87 flights with suspected/confirmed exposure to oil fumes at one major US airline, and identified a significant proportion of flights with symptomatic crews inflight and post-flight, necessitating emergency medical care, lost work time, and follow up medical care. The airline significantly underreported these events to the FAA. Crewmember reports of inflight symptoms raise concerns about safety of flight.)

9. **AAIB (2009) Bulletin no. 6/09, Boeing 757, G-BYAO (EW/C2006/10/8), UK Air Accidents Investigation Branch, UK Department for Transport** (UK accident investigative report describes incident during which pilots donned oxygen and declared MAYDAY upon exposure to oil fumes inflight. Maintenance staff returned the aircraft to service prematurely because their efforts to identify the fumes source on the ground did not include high-power engine runs. The fumes returned on the subsequent flight. AAIB recommended that Boeing explicitly include high power engine runs in its "fault isolation manual" for maintenance in response to oil fume exposures, and reiterated its 2007 recommendations to EASA/FAA for a flight deck warning system for oil fumes in the bleed air.)

10. **ASHRAE (2009) Letter from ASHRAE President to the FAA and EASA dated 9 March 2009, urging those agencies to determine the requirements for bleed air cleaning and monitoring given the evidence that flight safety can be compromised when pilots are exposed to oil fumes.** (Industry and labor members of the ASHRAE aircraft air quality committee unanimously approved the letter at their January 2009 meeting in Chicago, IL.)

11. **RNF (2009) "Final report: Aircraft serious incident – Smoke in flight deck and cabin, engine shut-down and emergency landing" Icelandic Aircraft Accident Investigation Board (Rannsóknarnefnd flugslysa), Reykjavik, Iceland** (Icelandic authority reported on a smoke/fumes incident during the climb phase of flight on a B757. A worn fuel pump failed during climb, which allowed fuel to contaminate the

engine oil reservoir. The engine seals could not contain the fuel/oil mixture, so it leaked into the engine compressor and contaminated the bleed air. The cabin and flight deck filled with white smoke and the captain initiated a diversion. The report notes that "aircraft system design weakness was revealed, as smoke could travel unnoticed and unhindered from the engine and to the flight deck.")

12. **CAA (2008) "Flight Operations Department Communications (FODCOM) 17/2008" UK Civil Aviation Authority, Safety Regulation Group, Aviation House, Gatwick, West Sussex, England** (UK aviation regulator recommends that airlines ensure that flight crew are trained to immediately don oxygen masks if smoke/fumes are suspected.)

13. **AAIB (2007) Bulletin no. 4/2/07, Bombardier DHC-8-400, G-JECE (EW/C2005/08/10), UK Air Accidents Investigation Branch, UK Department for Transport** (UK accident investigative report recommends that the FAA and EASA require a flight deck detection and warning system for oil smoke/mist given evidence of compromised flight safety when pilots are exposed to oil fumes.)

14. **ATSB (2007) "Pilot incapacitation: analysis of medical conditions affecting pilots involved in incidents and accidents 1 January 1975 to 31 March 2006" Australian Transport Safety Bureau, Aviation Research & Analysis Report – B2006/0170** (Australian aviation safety authority reports that the second most common cause of pilot incapacitation was due to toxic smoke/fumes, of which 25% were due to carbon monoxide.)

15. **Boeing (2007) Health hazard warnings listed on Safety Data Sheet for aviation engine oils (MSDS #138541)** ("Exposure [to oil fumes] may cause irritation characterized by tears, redness, burning sensation (eyes), redness, swelling or cracking of skin, or burning sensation in the nose, throat, and lungs (inhalation). Neurotoxicity may be characterized by dizziness, headache, confusion, and "intoxication.")

16. **SAE (2005) Aerospace Information Report 4766/2 "Airborne Chemicals in Aircraft Cabins" Society of Automotive Engineers-Aerospace, Warrendale, PA** (Technical report that describes how oil fumes can contaminate the aircraft air supply system and details flight safety concerns including crew incapacitation or impairment, increased crew workload due to use of emergency procedures/change in flight plan, and inadequate protections for passengers.)

17. **SAAIB (2006) "Investigation report concerning the serious incident to aircraft AVRO 146-RJ 100, HB-IXN operated by Swiss International Air Lines Ltd. Under flight number LX1103 on 19 April 2005 on approach to Zurich-Kloten airport" Swiss Aircraft Accident Investigation Bureau, Berne, Switzerland** (Swiss aviation safety authority attributes inflight incident of copilot incapacitation on approach to exposure to oil fumes that could have been prevented.)

18. **AAIB (2004) Report no. 1/2004, BAe146, G-JEAK (EW/C2000/11/4) UK Air Accidents Investigation Branch, UK Department for Transport** (UK accident investigator attributes pilot and copilot impairment inflight to an APU oil leak.)

19. **CAA (2004) "Cabin air quality" CAA Paper 2004/04, Research Management Department, Safety Regulation Group, UK Civil Aviation Authority, Aviation House, Gatwick Airport South, West Sussex, UK** (As part of an investigation into pilot incapacitation, UK regulator sampled duct linings on two commercial aircraft and identified TCP oil additives.)

20. **FAA (2004) "Airworthiness Directive 2004-12-05: BAE Systems (Operations) Limited Model BAe 146 Series Airplanes" Docket No. 2003-NR-94-AD, Federal Aviation Administration, Washington, DC** (US aviation regulator acknowledges that exposure to oil fumes can cause impairment of flight deck crew and impair flight safety.)

21. **Bobb, AJ and Still, KR (2003) "Known harmful effects of constituents of jet oil smoke," TOXDET-03-04, Naval Health Research Center Detachment (Toxicology), Wright-Patterson AFB, OH** (US military researchers refer to chronic neurological effects associated with exposure to carbon monoxide and TCP oil additives on aircraft in operation, even at doses below the recognized threshold for acute exposure, and challenge the relevance of oral toxicity studies of engine oils.)

22. **NRC (2002) "The Airliner Cabin Environment and The Health of Passengers and Crew," (excerpt) US National Research Council, ISBN 0-309-08289-7, National Academy Press, Washington, DC** (Report recommends that the US aviation regulator require bleed air monitoring with flight deck indication and investigate/report on the need for and feasibility of installing air cleaning equipment to address bleed air contamination during ground operation, normal flight, and air-quality incidents.)

23. **CAA (2002) "Flight Operations Department Communications (FODCOM) 21/2002" UK Civil Aviation Authority, Safety Regulation Group, Aviation House, Gatwick, West Sussex, England** (UK aviation regulator recommends that airlines ensure that flight crew are trained to immediately don oxygen masks if smoke/fumes are suspected and that flight/cabin crew are advised of necessary post-flight actions following exposure to smoke/fumes. Note: In Feb. 2011, the CAA republished part of this document as "CAP 789: Requirements and guidance material for operators.")

24. **SHK (2001) "Report RL 2001:41e "Accident investigation into incident onboard aircraft SE-DRE during flight between Stockholm and Malmo M County, Sweden," Statens Haverikommission Board of Accident Investigation, Stockholm, Sweden** (Report on pilot incapacitation during a commercial flight in Sweden involving an engine oil leak. Because measured levels of oil-based contaminants were below occupational exposure limits, the report did not definitively attribute pilot incapacitation to oil fumes, but rather, exposure to "probably polluted air." Investigators recommended that flight crew be trained to immediately don oxygen and that airlines develop an action plan for crews and aircraft after landing.)

25. **CAA (2001) "Flight Operations Department Communication (FODCOM) 14/2001" UK Civil Aviation Authority, Safety Regulation Group, Aviation House, Gatwick, West Sussex, England** (UK regulator recommends that airlines train flight deck and cabin crew to recognize and respond to toxic fumes caused by engine/ECS malfunction that could incapacitate them inflight. This includes training cabin crew to monitor the flight deck if smoke/fumes are present or suspected.)

26. **CAA (2000) "Flight Operations Department Communication (FODCOM) 17/2000" UK Civil Aviation Authority, Safety Regulation Group, Aviation House, Gatwick, West Sussex, England** (UK aviation regulator notes that one or both pilots can be incapacitated by exposure to oil fumes and recommends that airlines educate flight deck and cabin crew that one or both pilots can be incapacitated by exposure to smoke/fumes, and train flight deck crew to don oxygen masks immediately.)

27. **PCA (2000) "Technical report on air safety and cabin air quality in the BAe146 aircraft," (excerpt) Parliament of the Commonwealth of Australia, Senate Rural and Regional Affairs and Transport Legislation Committee, Senate Printing Unit, Canberra, Australia** (Australian Senate committee report concluded that health/safety problems reported by crewmembers are not unique to the BAe146 aircraft (Sec. 6.2), that pilots underreport fume events (Sec. 6.18), and that the Australian aviation authority should introduce regulations specifying air quality monitoring and compulsory reporting requirements for all passenger jet operators (Ch. 6, Rec. 1 and 3).)

28. **ATSB (1999) "British Aerospace Plc BAe 146-300, VH-NJF. Occurrence brief no. 199702276," Australian Transport Safety Bureau, Canberra, Australia** (Australian accident investigator reported on an incident during which two of three flight crew members experienced symptoms that prevented them from carrying out their flying duties. The report noted that oil fume events are not new, rare, or specific to one aircraft type. It expressed "particular concern" over flight safety implications of exposure and recommended further investigation into the health impact on passengers and crew.)

29. **Lipscomb, J; Walsh, M; Caldwell, D; et al (1995) "Inhalation toxicity of vapor phase lubricants" AL/OE-TR-1997-0090, US Air Force Armstrong Laboratory, Occupational and Environmental Health Directorate, Toxicology Division, Wright-Patterson AFB, OH** (USAF-commissioned study exposed rats to oil fumes. Report notes a greater neurotoxic impact associated with inhalation of TCP oil additives than with oral dosing. Authors recommend particular caution when working with vapor phase lubricants that contain TCPs.)

30. **Kelso, AG; Charlesworth, JM; and McVea, GG (1988) "Contamination of environmental control systems in Hercules aircraft: MRL-R-1116, AR-005-230," Australian Government Department of Defence, Defence Science and Technology Organisation, Melbourne, Victoria, Australia** (Royal Australian Air Force report describes air sampling conducted on Hercules aircraft. Measurements confirm exposure to hydrocarbons as well as TCPs in the air filter bags. Authors recommend that charcoal filters for the bleed air supply be investigated.)

31. **Rayman, RB and McNaughton, GB (1983) "Smoke/fumes in the cockpit" Aviat. Space Environ. Med., 54(8): 738-740** (Review of 89 smoke/fume events on US military aircraft from 1970 to 1980, many of which were described as "incapacitating to some degree." Article concludes that "smoke/fumes in the cockpit is not a rare event and is a clear threat to flight safety.")

32. **Paciorek, KL; Nakahara, JH; Kratzer, RH (1978) "Fluid contamination of aircraft cabin air and breathing oxygen" SAM-TR-79-34, Report by Ultrasystems Inc. for USAF School of Aerospace Medicine, Aerospace Medical Division, Brooks AFB, Texas** (USAF-commissioned investigation into the

impact of fluid contamination on aircraft cabin air and breathing oxygen. Researchers measured "significant quantities of toxic compounds" when a line rupture was simulated onto a hot surface.)

33. **Montgomery, MR; Wier, GT; Zieve, FJ; et al (1977) "Human intoxication following inhalation exposure to synthetic jet lubricating oil," Clin. Toxicol., 11(4): 423-426** (Case study of acute intoxication by a navigator on a C-130A aircraft due to exposure to engine oil fumes inflight. He experienced neurological impairment and gastrointestinal distress and "by the time the plane landed, he had difficulty standing.")

34. **NTSB (1984) "Special Investigation Report: An evaluation of the Garrett TPE 331 engine's potential for turbine oil byproduct contamination of an aircraft cabin environmental system" NTSB/SIR-84/01, PB84-917006, National Transportation Safety Board, Washington, DC** (The NTSB reviewed the reports of 10 unexplained crashes, all on turboprops equipped with the same engine type, and launched an inquiry into whether or not exposure to aerosolized engine oil could explain the pilot incapacitation. The agency acknowledged that "the potential flight safety issue concerns all turbine engines using synthetic turbine oil and supplying compressor bleed air for the aircraft cabin environmental control." The NTSB partnered with the two parties that had the most to lose if a positive association was found, and introduced a known quantity of Exxon 2380 engine oil into the compressor section of a Garrett TPE331 engine. The team measured the oil-based airborne contaminants downstream of the compressor section that, on an aircraft, would be released into the flight deck air. However, in all but one trial, they installed a glass filter in the sampling line and only measured the gaseous contaminants, even though bleed air on the incident aircraft had not been filtered. In that one trial, the researchers collected unfiltered oil mist on a filter, but for a shorter duration (15 minutes) and at a low temperature (160°F). Even though the test conditions did not reflect the on-aircraft conditions, the study concluded that "no evidence was developed to support the hypothesis of pilot incapacitation due to bleed air contamination.")

35. Crane, CR; Sanders, DC; Endecott, BR; et al (1983) "Inhalation toxicology: III. Evaluation of thermal degradation of products from aircraft and automobile engine oils, aircraft hydraulic fluid, and mineral oil," Aviation Medicine Report FAA AM-83-12, Civil Aeromedical Institute, US Federal Aviation Administration, Oklahoma City, OK (FAA researchers exposed rats to smoke/fumes generated by heating 3ml samples of engine oils from 300-600°C, and noted time to incapacitation and death. The team assumed that carbon monoxide (CO) was the most toxic constituent of oil fumes, and surmised that there would have been inadequate CO to explain pilot incapacitation on the 10 crashed planes. They did not appear to consider that the pilots would have been exposed to CO under reduced cabin pressure (and, thus, reduced oxygen) conditions, and with likely co-exposure to PAN which would have further impaired oxygen-carrying capacity of hemoglobin. The researchers did acknowledge that if the oil fumes in the bleed air tested by the NTSB study had not been filtered – as on the crashed aircraft - then "a significant toxicity could be associated with breathing oil mist.")

36. **Treon, JF; Cappel, JW; Cleveland, FP; et al. (1955) "The toxicity of the products formed by the thermal decomposition of certain organic substances." Am Ind Hyg Assoc Quarterly, 16(3): 187-195** (US Air Force-commissioned study with test animals inhaling pyrolyzed aviation engine oils. Authors

concluded that inhaling the heated oils increased the toxicity considerably and that exposure to the oil fogs “produced pneumonitis and degenerative changes of the brain, liver, and kidneys.”)

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