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SIoBiA - Safety Implication of Biofuels in Aviation

SAFETY IMPLICATION OF BIOFUELS IN AVIATION

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1 Introduction and Outline of Work

Biofuels potentially interesting also for aviation purposes are predominantly liquid fuels produced from biomass. The most common biofuels today are biodiesel and bioethanol. Since diesel engines are rather rare in aviation this survey is focusing on ethanol admixed to gasoline products.

The Directive 2003/30/EC of the European Parliament and the Council of May 8th 2003 on the promotion of the use of biofuels or other renewable fuels for transport encourage a growing admixture of biogenic fuel components to fossil automotive gasoline. Some aircraft models equipped with spark ignited piston engines are approved for operation with automotive gasoline, frequently called “MOGAS” (motor gasoline). The majority of those approvals is limited to MOGAS compositions that do not contain methanol or ethanol beyond negligible amounts. In the past years (bio-)MTBE or (bio-)ETBE have been widely used as blending component of automotive gasoline whilst the usage of low-molecular alcohols like methanol or ethanol has been avoided due to the handling problems especially with regard to the strong affinity for water. With rising mandatory bio-admixtures the conversion of the basic biogenic ethanol to ETBE, causing a reduction of energetic payoff, becomes more and more unattractive. Therefore the direct ethanol admixture is accordingly favoured.

Due to the national enforcements of the directive 2003/30/EC more oxygenates produced from organic materials like bioethanol have started to appear in automotive gasolines already. The current fuel specification EN 228 already allows up to 3 % volume per volume (v/v) (bio-)methanol or up to 5 % v/v (bio-)ethanol as fuel components. This is also roughly the amount of biogenic components to comply with the legal requirements to avoid monetary penalties for producers and distributors of fuels.

Since automotive fuel is cheaper than the common aviation gasoline (AVGAS), creates less problems with lead deposits in the engine, and in general produces less pollutants it is strongly favoured by pilots. But being designed for a different set of usage scenarios the use of automotive fuel with low molecular alcohols for aircraft operation may have adverse effects in aviation operation. Increasing amounts of ethanol admixtures impose various changes in the gasoline’s chemical and physical properties, some of them rather unexpected and not within the range of flight experiences even of long-term pilots.

After a frame-setting failure mode and effects analysis (FMEA) that highlighted the predominant threats of ethanol present in future MOGAS sorts the most problematic objectives have been investigated in further detail, both by theoretical investigations and practical exemplary flight and test rig experiments. Even if the general level of pollutant emissions is usually reduced by utilization of biogenic components in the fuel it cannot be excluded straight away that also undesired side-effects, both on a local and global scale, may be incurred, e.g. by super- or sub-stoichiometric combustion typical in aviation operation. Accordingly, another aspect under investigation is the life cycle analysis of the usage of ethanol admixed gasoline for aviation purposes.

Lastly, prior reports identified water as one of the most problematic substances for fuel handling and utilization in the area of aviation. There is no simple, practical measurement tool for the assessment of solved water content in gasoline so far, however. Accordingly it is one of the aims of this report to identify potential respective measurement procedures that deem promising for a development of such instrumentation.

The EASA call for tenders, based on previous information gathering, already collected most of these issues and formulated several basic objectives. The results of this report necessitated a slightly different internal logical structure to adequately organize the acquired knowledge, though. Therefore the referencing of the tender's topics is included in the individual section headings:

T 1: Literature scan and statistical data gathering
T 2a: Phase separation
T 2b: Icing
T 2c: Long term storaging of gasoline
T 3: Vapour locking
T 4: Compatibility of materials
T 5: Life cycle analysis of ethanol admixed gasolines
T 6: Potential methods of water in gasoline detection
T 7: FMEA on functions and parts

The sections have been assembled in a different order that is more oriented towards easier reading and logical interconnection of topics. The main part of the report is followed by a series of annexes documenting the immediate work of cooperation partners, and additional tabulated results referenced in the main part.

2 Summary and Recommendations

In its effort to introduce regenerating and hence sustainable energy resources into the existing combustibles mix, recent European legislation enforces the admixture of biogenic fuels into conventional fossil gasoline. For economic reasons this is, as of today, mainly ethanol. Compared to the fossil gasoline ingredients ethanol has a different chemical structure, leading to a potentially dangerous physico-chemical behaviour, especially in the presence of water. As there is a stronger economically driven tendency to use vehicle gasolines as aviation fuel this may lead to potentially dangerous scenarios especially in the operation of the smaller General Aviation aircraft.

The SIoBIA study addresses these scenarios by an in-depth study on the various potential threats imposed by ethanol admixtures up to 15 % v/v.

First, a failure mode and effects analysis has been performed. For the current fleet of General Aviation aircraft the associated individual threats (phase separation, vapour locking, icing, material compatibility) were confirmed on the parts and functional levels by an expert group. The span of risks covers the range of "just a nuisance" to "deadly dangerous if not adequately and pro-actively handled". For the major threats a clustering of recommendations for a further treatment of the identified issues has been given.

A statistical analysis of European aircraft numbers and types, reconciling several base data sets on European General Aviation, lead to an assessment of the number of potentially affected aircraft. About 20,000 aircraft ($\approx 10\,\%$) throughout Europe are either directly or potentially endangered by the various negative effects of an ethanol admixture in the nearer future.

The consecuting theoretical and practical work highlighted the most prominent threats in parallel tasks, namely water-induced phase separation, carburettor icing, vapour locking by gasoline brand mixing, construction material compatibility, and proactive water detection in the fuel system. These threat investigations were flanked by a life cycle analysis on the environmental impacts of ethanol addition to aircraft fuels.

Especially for the vast majority of existing carburettor engines there are various general threats stemming from ethanol-admixed gasolines, potentially leading to disrupted engine operation. Some of them are readily encountered by sensitive operation and increased maintenance efforts, while others may occur rather unexpectedly during a flight mission, even to the point that the engine(s) will stall and not start again, so an unmotored emergency landing has to be performed.

Main issues are

- the material compatibility of hitherto only gasoline-exposed fuel system parts, especially elastomers and sealants,
- the danger of phase separation in water containing gasoline if the fuel is stored for prolonged periods in vented aircraft tanks, and if it is inevitably cooled down during a flight,
- the increased likelihood of a vapour lock due to increased vapour pressure of gasolines mixtures of different ethanol abundancies if the first fuel pressure raising pump is not in a cold section of the fuel system, and the
- carburettor icing due to raised enthalpy of evaporation for ethanol-admixed gasolines if there is no additional heat input into the intake air,

The experiences from vehicle technology may, to a rather great extent, be transferred to the operating conditions of ultralights. Here rather modern engine technology prevails, and the usually low service ceiling keeps temperature change effects below an acceptable bound. Other types of General Aviation aircraft are more prone to run into difficulties due to their markedly higher service ceiling and the resulting major differences in temperature and ambient pressure, as well as their longer conceptual histories, leading predominantly to material compatibility problems. For those major threats intensive studies and results, as well as respective guidelines, are given in this report. Further recommended activities are listed below.

Material incompabilities should be explicitly addressed in airworthiness qualification and certification processes, even for replacement parts. A comprehensive study of all materials used in the past 50 years for certified aircraft construction is not feasible. Only general guidelines for future material selection or replacement can be given in this report.

A crucial point in phase separation avoidance is a strict proactive control on the occurrence of *solved* water in the gasoline. Unluckily there is no practical and affordable test procedure at hand as of today even though some measurement principles indicate the potential of creating a respective tool.

Life cycle analysis showed that substantial green-house gas (GHG) savings are possible if ethanol is admixed to conventional gasoline in the amounts discussed in this report. This effect is mostly related to the old, but reliable technology and the non-existence of exhaust gas catalyzers in aviation: While the savings through replacing fossil fuel by biogenically produced ethanol are at least detectable the major effect stems from the combustion process itself, as it is cleaner and produces less GHG emissions in the presence of ethanol.

Most of the endangering issues would presumably vanish if butanol would be deployed as biogenic supplement of the fossil fuels as its longer hydrocarbon tail provides much more affinity to the non-polar gasoline majority ingredients. Butanol would exhibit other advantages as well: Compared to ethanol its energy content is larger, and it would presumably have less effect on the vapour pressure if gasolines of different admixture levels are mixed. Presently there is no commercially viable biogenic supply path, even though some promising exploratory efforts exist [16]. Should this alternative of biogenic admixing be pursued in future its effects should be studied in detail in a follow-up project as there is no practical experience on butanol-admixed gasolines deployment in aviation as of today.

The SIoBIA study sheds light on the present status of the most problematic issues with respect to ethanol admixtures in aviation gasoline, but partially only up to the point that further investigations and research should be undertaken to get in-depth and directly practical information. The following topics are suggested for further activities:

- **Investigations on the bubble creation behaviour (threat of vapour locking) of a larger number of commercially sold gasolines and their potential mixtures.** Different compositions of gasolines are likely to affect the vapour bubble creation, especially so if encountering unforeseen amounts of ethanol due to a mixing of residues in the aircraft's tank. As a result a matrix of potential mixing scenarios should be collected and progressively filled over time as new brands with differing ethanol content appear on the market. The tests should be performed especially with raised temperatures in an dynamic manner, simulating those of common aircraft fuel systems. If possible, a maximum operation temperature and/or maximum service ceiling should be identified and published on a work-in-progress basis on a freely accessible web site.
- **Determination of the temperature-depending maximum solved water abundancies for a larger number of commercially sold gasolines, potentially in combination with random**

sampling results on water content. The outcome of these investigation could yield a definition of a conservative envelope of tolerable water in gasoline contents. This value is becoming more and more of interest as the bearing capability increases with increasing amount of ethanol there is no normative numerical upper limit of water content in gasolines as of today.

- **Quantitative determination of water absorbed out of the tank venting air.** Temperature inversion in the tank of a descending aircraft may lead to a significant absorption of humidity due to the rather large air volume throughput rates of venting. Here experiments for temperature and humidity niveau determination, in combination with a theoretical study taking into account knowledge of the atmospheric states and compositions, should be performed to determine quantitative water balances.

- **Research and/or development of a practical sensor for water solved in gasoline.** The water content of present gasolines is reportedly well above zero and a potential object of future economical optimization with respect to gasoline price fixations as there is no normative quantified upper limit in the gasoline composition definitions. Reported field tests with hydrous E-15 [21], saving the expenses of providing super-azeotropic ethanol provision for gasoline admixing, already point in this direction. As this will foreseeably not create a problem for ground based locomotion, contrary to aviative purposes with its strong temperature decrease in the gasoline tanks, the pilot should be equipped with a practical method of solved water determination.