CONCEPT OF POL MOBILE LABORATORY FOR JP/F-34 AVIATION FUEL QUALITY VERIFICATION

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Abstract: The article deals with the concept of a new mobile fuel laboratory, which will enable the verification of the quality of JP/F-34 aviation fuel. Using external benchmarking, a multi-criteria analysis and subsequent comparison of analogous solutions at national and international level is performed. Focus is placed on fulfilling the requirements of the Army of the Czech Republic to verify the quality of JP/F-34 type aviation fuel in accordance with the relevant national and international technical standards, including the logistical support of the laboratory. The concept of a set of modular ISO 1C containers with corresponding laboratory equipment and estimation of capacities for practical use in the conditions of the Czech Army is proposed. It includes 3D visualization of the proposed mobile container laboratory - ISO 1C modular container set.

Keywords: POL laboratory, mobility, aviation fuel, quality, ISO 1C container.

1 Introduction

One of the key challenges of aviation logistics is the refueling of aviation fuel, and it is not only about quantitative requirements, but also about qualitative requirements, which are very strict in the case of aviation equipment. The article focuses mainly on the qualitative part, i.e. the verification of the quality of aviation fuel. If we proceed from the paraphrase of the quality (quality) from the nomenclature of ISO (International Organization for Standardization) 9000 series standards, the quality represents the fulfilment of the requirements of the Army of the Czech Republic (ACR), respectively the North Atlantic Treaty Organization (NATO), by a set of inherent product characteristics.(1) Product characteristics in this case mean normatively determined fuel parameters in accordance with technical standards (mainly VJS 1-3-L (2)).

From the perspective of the ACR practice, the quality of fuel, especially aviation fuel, has been dealt with within the Quality Control System since the inception of the Fuel and Lubricants Service in the 1950s.

From the point of view of Lessons Learned, the capabilities of the Czech Armed Forces were not adequately built due to the performance of tasks in multinational operations where there was an absolute dependence on the provision of aviation fuel by the armies of NATO member states, which, thanks to their technical equipment, can handle the acceptance from local suppliers according to the requirements of the relevant NATO standardization agreements - STANAG 3747 (3) and STANAG 1110 (4) , therefore in adequate quality. Because of the assumption of further deployment in multinational task forces only, no building of own capabilities took place.

Gaining the capability to verify the quality of aviation fuel is necessary in order to gain independence from the logistic support of other states and possible logistic support of allied forces, and it is proposed to equip the Czech Armed Forces with a mobile container laboratory in accordance with the relevant standards (see above), analogous to the selected armies of NATO member states, e.g. the United States of America (Figure 1), Germany, Hungary or France.

The aim of the paper is to present the concept of a mobile PHM laboratory, including a comparison with currently used systems.

Figure 1. Petroleum Quality Anlysis System – Enhanced, Author: Sgt. George W. Slaughter

2 Methods and data

The paper is mainly prepared using a variety of analytical methods. The current state of aviation fuel quality verification is critically analyzed and then the output is synthetically generalized in the form of a proposed solution using current technical and technological trends. It also includes a comparison of possible approaches using multi-criteria analysis (specifically the weighted sum method), which allowed the ordinal ranking of the considered options in descending order. It includes quantitative and qualitative criteria determined on the basis of their impact on the operation of the mobile PHM laboratory and user comfort

The data basis for the analyses and proposals were both the specific tactical and technical data of individual systems (variants) resulting from the implemented public contracts (criteria k1 to k5) and the results of a questionnaire survey among the professional POL community of the Czech Air Force bases with a 100% return rate. A separate part was the weights of individual criteria - their significance in the comparative analysis, which were also based on the questionnaire survey of the given group of experts. The identified preferences were consolidated into the resulting weight vector, using which the utility functions of interest were calculated within the framework of the multi-criteria evaluation of the variants.

3 Current state and system requirements

The Logistics Section of the Ministry of Defense of the Czech Republic, the Logistics Agency and the Air Force are currently gathering specific requirements from air bases and the Central POL Laboratory in Brno for the content and possible functionality of a mobile POL laboratory that could be placed in the ISO 1C container(s).

The need for such a laboratory is not only based on the requirements of the Czech Armed Forces, but also on its justified use in all places where helicopter technology is present. A mobile fuel container laboratory would greatly simplify the process of receiving and distributing fuel (in general), whether from the State Material Reserve Administration (SMRA) or from any civilian distribution network or pipeline. The containerized workplace with a mobile laboratory can be placed on any flat paved surface (max. with a slope of 5%) at an optimal distance from the deployment site (emergency), during the shutdown of the permanent laboratory or for the support of the airborne equipment of the Integrated Rescue System (IRS) of the Czech Republic during its long-term deployment in inaccessible terrain (e.g. forest fire, floods) and for the air rescue service.

Currently, the Air Force bases have the REO C-test/F-34 Portable Laboratory Kit (5), which is primarily designed to verify the basic quality parameters of F-34 fuel under field conditions at the Type C test level and can also be used for other fuels such as Jet A-1 or F-54 diesel fuel.

The kit is placed in a stainless-steel travel box and all work with it is dependent on specially trained operators carrying out the relevant testing.

It is approved for use in dust-free, weatherproof locations with minimal humidity. Functionality shall be ensured when connected to electricity and in a location with the possibility of handling Class I and Class II combustibles. (6) The mobile laboratory shall serve not only for the actual performance of laboratory analyses and tests, but also as a storage facility for samples, sample tubes, a collection point for hazardous waste arising from the performance of analyses, an evaluation workplace and, last but not least, as a facility for the laboratory staff. The PHM laboratory is equipped with all the necessary sampling equipment in accordance with EN ISO 3170 Liquid petroleum products - Manual sampling. It is also equipped with the measuring and testing equipment necessary for the correct performance of the tests, including manuals supplied by the manufacturers of each piece of equipment. The equipment and its software used for testing, calibration and sampling shall achieve the required accuracy and comply with the specifications and test standards applicable to the tests. (6)

The POL laboratory shall have technological procedures for the safe handling, transport, storage and use of reference standards, materials and samples and procedures for scheduled maintenance of measuring equipment.

For independent operation of the fuel management, the laboratory must encompass the scope of the B-1 and C-1 type tests (7), see. Table 1.

Table 1. Tests required for JP/F-34 aviation fuels (7)

Tested parameters	Type of test	
	B-1	C-1
Appearance and impurity content (visually)	X	X
Color (visually)	X	X
Density at +15 °C	X	X
Distillation test	X	X
Corrosion on copper	X	
Crystallization point	X	
Content of resinous substances	X	
Pressure according to Reid	X	
Flash point in a closed crucible	X (only F-40)	
Reaction with water	X	X
Content of mechanical impurities (gravimetrically)		X
Freezing additive content	X (only F-34, F-40, F-44)	X (only F-34, F-40, F-44)
Electrical conductivity	X (not F-44)	X (not F-44)

If the prescribed instrumentation is expanded to include an open cup flash point test (Cleveland) and kinematic viscosity, the mobile laboratory will increase its utility value and " upgrade" to a fully autonomous laboratory also in terms of verifying the quality of aviation engine oil and the purity of aviation hydraulic fluid.

4 Mobile POL laboratory concept

The design of the instrumentation of the mobile fuel laboratory for the F-34 type aviation kerosene is based on the American Society for Testing and Materials (ASTM) standards (8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22) which are binding for the ACR by way of the approved Military Quality Specifications. The standard addresses the minimum technical equipment to perform the various required tests (listed in Table 1 above) for the analysis of aviation fuel with respect to its mobile use outside the permanent laboratory.

Considering the experience with currently used systems, which are used cross-sectionally in various armies (e.g. Hungary, the United States, Poland), the requirements for a mobile laboratory can be met by two approaches - variants. Both variants are standardly used by the Army for similar applications. Historically, the more widespread is the construction of a tent variant in the form of e.g. the inflatable tent DIT/044CZ, which is currently replaced in various applications by a modular solution using standardized ISO series 1 containers. (23)

For operational and ergonomic reasons, it is more suitable to place the equipment of all workplaces in a set of two interconnected, demountable containers, where in one of them it is planned to place technological equipment, including water distribution, gas (from a pressure cylinder), collection containers and a spare source of electricity. In the second one, it is planned to carry out tests less demanding on instrumentation: electrical conductivity, density, fuel-water reaction, mechanical impurities content by colorimetric method, as well as evaluation and recording of results, storage of armament and equipment. The arrangement of handling and storage spaces within the container set offers variability in the placement of measuring instruments.

The material solution of the handling surfaces is made of stainless steel, which is resistant to the chemical effects of petroleum substances and is easy to maintain.

An integrated part of the container set is an electric power plant ensuring the independence of the mobile laboratory from the electricity supply. Solar panels can also provide an additional, noise-free source. A fume hood for explosive environments and a water spout are installed at the same time.

5 Multi-criteria evaluation of variants

For the comparison of the variants, 12 criteria were set, where the values of the first 5 quantitative criteria are based on the procurement of analogous material. The values of the remaining 7 qualitative criteria were determined by a questionnaire survey focusing on user comfort during testing, provision of facilities, sample handling, maintenance and the possibility of arranging the necessary equipment for the PHM laboratory. Respondents were given a choice of three options for each question based on their preferences: A set of two ISO 1C containers, an inflatable tent, or no preferred option. The results for each question can be seen in Table 2. It is clear that the expert community clearly chose option B, the combination of two ISO 1C containers. For each criterion, this option was chosen by between 65% and 85% of all respondents.

Table 2. The values of the criteria of each of the compared variants

Criterion	Option A - Tent DIT/044CZ	Option B - Container ISO 1C	Type of criterion
Initial economic cost (CZK)	1 572 000	1 662 540	Minimizing
Dimension in unfolded state (m²)	49,83	29,54	Minimizing
Deployment time (min)	120	30	Minimizing
Minimum use	–40	–32	Minimizing

temperature (°C)			
Maximum use temperature (°C)	55	50	Maximizing
C1 examination performance (%)	16,67	83,33	Maximizing
B1 examination performance (%)	16,67	83,33	Maximizing
Record-keeping, evaluation (%)	16,67	83,33	Maximizing
Background for time out of service (%)	33,33	66,67	Maximizing
Storage and handling of samples (%)	16,67	83,33	Maximizing
Cleanliness and sterility maintenance (%)	16,67	83,33	Maximizing
Workplace layout variability (%)	28,57	71,43	Maximizing

From an economic point of view, mobile testing of POL using an inflatable tent (model option A) appears to be more advantageous, assuming the same laboratory equipment is placed in the insulated transport boxes, where the costs can be considered identical. It can be assumed that the option using two ISO containers (model option B) will be more expensive (depending on the specific public contract and the tendered price). The use of standardised furniture commonly used in the Czech Armed Forces can be assumed for variant A. The equipment for variant B is assumed to be 'tailor-made', which offers greater personalisation and adaptation to the comfort requirements when working with measuring instruments at a higher cost.

Using multi-criteria analysis, the two variants (A and B) are compared to ordinally determine the value of a utility function that identifies the more appropriate variant in relation to the criteria values and weight vector. In general, the multi-criteria variant evaluation matrix can be described as follows:

A list of possible variants (1, 2 to n) is given:

$$A = \{a_1, a_2, ..., a_n\}$$

Then a list of evaluation criteria (1, 2 to k):

$$Y = (y_{ij})$$

According to these criteria, each variant ai, i = 1, 2, ..., n is described by a vector of criterion values (yi1, yi2, ..., yik). This results in a mathematical model of the multi-criteria variant evaluation problem expressed in the form of a criterion matrix:

$$Y = (y_{ij})$$

The criterion matrix can generally be written as follows:

$$Y = \begin{pmatrix} y_{11} & y_{12} & \cdot & \cdot & \cdot & y_{1k} \\ y_{21} & y_{22} & & & & y_{2k} \\ \cdot & & & \cdot & & \cdot \\ \cdot & & & & \cdot & \cdot \\ \cdot & & & & \cdot & \cdot \\ y_{n1} & y_{n2} & \cdot & \cdot & \cdot & y_{nk} \end{pmatrix},$$

After fitting the obtained values, the matrix is received:

$$Y= \begin{pmatrix} 83,33 & 83,33 & 83,33 & 66,67 & 83,33 & 83,33 & 71,42 & 1662540 & 29,54 & 0,5 & -32 & 50 \\ 16,67 & 16,67 & 16,67 & 33,33 & 16,67 & 16,67 & 28,57 & 1572000 & 49,83 & 2 & -40 & 55 \end{pmatrix}$$

According to Table 1, 8 of the 12 criteria are maximisation criteria. The first 4 criteria in Table 1 need to be converted to maximisation criteria. This is done using the following formula:

$$y_{ij} = \max(y_{ij}) - y_{ij}, \text{ i= 1,2, …, p, j = 1, 2, …, k}$$

The corresponding matrix is obtained:

$$Y= \begin{pmatrix} 83,33 & 83,33 & 83,33 & 66,67 & 83,33 & 83,33 & 71,42 & 0 & 29,54 & 1,5 & -32 & 50 \\ 16,67 & 16,67 & 16,67 & 33,33 & 16,67 & 16,67 & 28,57 & 90540 & 49,83 & 0 & -40 & 55 \end{pmatrix}$$

Since these are different quantities, measured in different units, it is necessary to normalize the matrix according to the following formula:

$$r_{ij} = \frac{y_{ij}-d_j}{h_j-d_j}, \text{ i= 1,2, …, p, j = 1, 2, …, k, where } d_j = \min(y_{ij}) \text{ and } h_j = \max(y_{ij}).$$

After fitting, a normalized matrix is obtained where all criteria are measured in the same (dimensionless) unit:

$$Y= \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 \end{pmatrix}$$

The questionnaire survey included the weighting of each criterion as shown in Table 3. The surveyed professional community was provided with a rating scale from 1 to 5, where the number 1 indicates the least and the number 5 the greatest importance of the respective criterion. The middle column shows the average value of the responses received and the right column shows the resulting weight of the criterion, which was calculated according to the following formula:

$$V_i = \frac{p_i}{\sum_{i=1}^{k} p_i}$$

Table 3. Weighting vector for each criterion

Criterion	Average value	Weight
C1 examination performance	4,66	0,123
B1 examination performance	4,66	0,123
Record-keeping, evaluation	3,83	0,101
Background for time out of service	3,66	0,096
Storage and handling of samples	4,33	0,114
Cleanliness and sterility maintenance	4	0,105
Workplace layout variability	3,66	0,096
Initial economic cost	1,16	0,029
Dimension in unfolded state	3,16	0,083
Deployment time	2,16	0,057
Minimum use temperature	1,33	0,035
Maximum use temperature	1,33	0,035

The preferred option is the one that maximizes the sum of the products of the criteria weights and the corresponding values from the normalized criterion matrix:

$$\sum_{j=1}^{k} v_j r_j \to max$$

After assigning specific values, the utility function of each of the considered options is calculated, and due to the maximization approach, option B can be considered more appropriate because it achieved a higher value of the utility function (Table 4).

Variant	$\sum_{j=1}^{13} v_j r_j \to max$	Ranking
A	0,123*0+0,123*0+0,101*0+0,096*0+0,114*0+ 0,105*0+0,096*0+0,029* 1+0,083*1+0,057*0+0,035*1+0,035*1 = 0,185	2.
B	0,123*1+0,123*1+0,101*1+0,096*1+0,114*1+ 0,105*1+0,096* 1+0,029*0+0,083*0+0,057*1+0,035*0+0,035* 0 = 0,815	1.

A multi-criteria evaluation of the options revealed a clear dominance of option B, i.e. 2 connected ISO containers, which is more than four times better than option A, i.e. the inflatable tent. The results are mainly based on a questionnaire survey that interprets the opinion of the professional community of the airport POL service of the ACR.

6 Mobile laboratory design

Due to the relatively clear result, where option B can be declared as clearly preferred, a visualisation of the possible layout of the mobile laboratory for aviation POL was developed. The visualisation is shown in Figures 2 and 3.

In developing the graphical design, consideration was given to the requirements of the ASTM standards described above, the requirements for sufficient space to accommodate the contemplated instrumentation, equipment and instrumentation, and the performance of administrative work. At the same time, material and colour design was considered to allow easy maintenance, high durability and user comfort.

The specific layout of the instruments and storage areas will be the subject of further research to find the optimum solution in terms of minimising time and distances between sites during standard POL analysis.

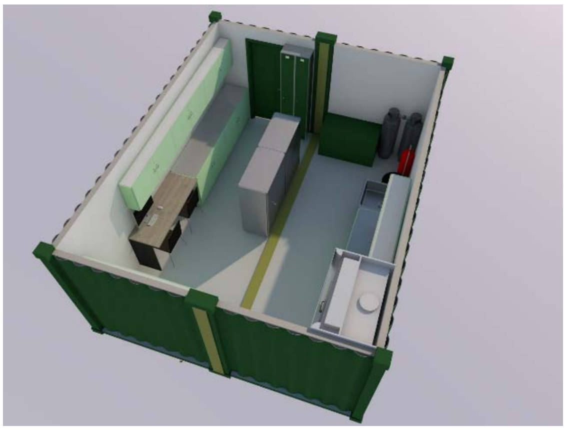

Figure 2. Mobile container laboratory design rear view

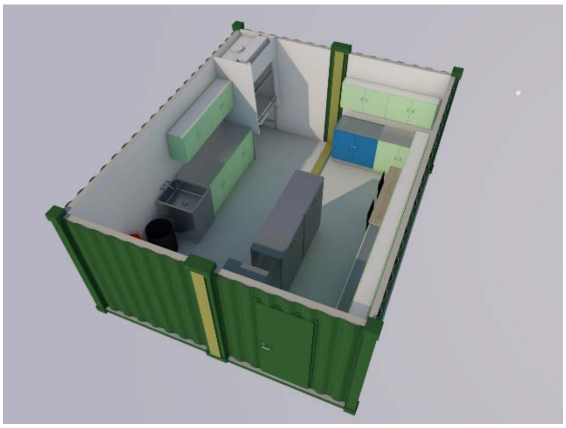

Figure 3. Mobile container laboratory design front view

7 Discussion

The presented concept of a mobile fuel laboratory for verification of JP/F-34 type aviation fuel can be considered as highly effective not only for normal peacetime operation in the conditions of the Czech Armed Forces, but especially for operational purposes, when the capability created in this way can be offered to the armies of NATO member states.

A presumption is to use the laboratory not only to verify Just-in-Case fuel from its own sources or from allies (either directly from the respective militaries or from Host Nation Support (HNS) sources), but also from local (unverified) sources, which would enable efficient use of fuel in the Joint Operation Area (JOA)

From the deployability point of view, the use of the ISO 1C container-based transport system is very suitable, which also allows a certain degree of modularity in the future in relation to new technologies and air force requirements.

8 Conclusion

Modern conflicts generally point to the rapid development of drones and other unmanned vehicles, which will also increase the logistical requirements for both aviation fuel and spare parts. New technologies are then linked to the increased sensitivity of engines and parts of aviation equipment to poor quality fuel. The presented preventive approach offers a solution and is based on the basic principle that prevention costs many times less than dealing with damage to government property following the use of poor-quality fuel.

The subject of further research will be the specific layout of the laboratory using the latest technologies in order to meet the requirements of the relevant standards. This will include defining specific capabilities at national but also international level to contribute to the NATO "pool" of capabilities to verify the quality of aviation fuel. An extension of the approach discussed will be a risk analysis in the context of the implementation of the container laboratory in multinational operations, including the inclusion of control activities for locally sourced fuels. Local sources may not only be the provider of low-quality fuel, but may also be purposefully degraded by an adversary or diversionary group. For example, water alone is sufficient to contaminate fuel, which is a potentially very effective, inexpensive, and simple way to disrupt the entire Air Force logistics chain.

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