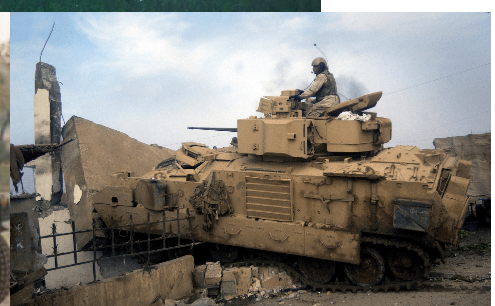
ARMY OIL ANALYSIS PROGRAM
JOINT OIL ANALYSIS PROGRAM

PLANS FOR HAND-HELD/PORTABLE OIL ASSESSMENT DEVICES



The way of the future....
Placing real-time oil assessment in the field
to keep our war-fighters safe and ready
while reducing maintenance costs

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **07 SEP 2005**	2. REPORT TYPE **Planning Document**	3. DATES COVERED **01-07-2005 to 07-09-2005**

4. TITLE AND SUBTITLE
Plans for hand-held/portable oil assessment devices

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Edward Urbansky

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Joint Oil Analysis Program Technical Support Center,85 Millington Avenue, Building 3887,NAS Pensacola,FL,32508-5020

8. PERFORMING ORGANIZATION REPORT NUMBER
JOAP-TSC-PD-U-05-04

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT
At the request of the U.S. Army Oil Analysis Program, the JOAP TSC conducted a market study, assembled a plan of action, and prepared a worksheet for the evaluation of portable or hand-held oil assessment devices. The document includes a review of the critical functions of motor oil, the factors to consider in selecting physicochemical properties for examination, and characteristics for ideal devices.

15. SUBJECT TERMS
oil analysis, oil assessment, portable, hand-held

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**12**	

THE PLAN

In an effort to decentralize testing and empower field units to assess oil quality on demand, the Army seeks to procure hand-held and/or portable oil assessment devices that provide the user a rapid means of screening oil and give a straightforward direction to change or retain the oil.

The JOAP TSC was asked to put together a plan for market research and feasibility. In conjunction with Army wishes, the TSC considered the factors that should play into selecting what to measure (see List 1) and the critical functions of motor oil (see List 2). Subsequently, the TSC set out to tabulate various measurable properties and rank them according to ease of testing, occurrence (how often the oil fails to perform), and criticality for proper function (Table 1). However, lack of access to the Army's database prevented the use of occurrence data for this effort.

Based on the Army's requirements, the TSC constructed specifications addressing three areas of performance: measurement and assessment, connectivity and electronics; and portability, usability, and durability. The TSC plan incorporates condition-based maintenance via limited wear debris analysis so long as it will be used to direct maintenance actions. Otherwise, the TSC recommends eliminating wear debris analysis altogether. The plan has several phases so that information gathered in each phase can be used to refine the subsequent phases and improve the overall results. Essentially, the optimal results will be the establishment of one or more CRADAs to develop prototype instruments appropriate for laboratory and eventually field testing.

Further communication with the Army indicated that the Oil Analysis Program staff settled on proceeding with six different types of assessment: kinematic viscosity, total acid number, total base number, water concentration, ethylene glycol concentration, and soot content. Accordingly, the TSC proposed performance criteria for those six tests and constructed a scoring sheet to be used for the demonstration phase.

A detailed description of the process follows....

Choosing what to test

In determining the properties or constituents worth measuring as an initial screening, there are three factors to consider in the selection process (List 1).

Ease of measuring a property depends on currently available technology, and that information is widely known. Ideally, *occurrence* information would be based on statistical models of historical data, but it can also be based on subsets of data and semi-objective inferrences from those data. Analogies from industrial data can also be used to predict the probability that the oil will fail to perform in a particular way. In evaluating the *criticality*, there are several issues we must consider in terms of the function of oil (List 2). Ideally, oil confers several benefits on moving and nonmoving parts. In each case, various properties are suggested by the roles the oil plays in the system.

In general, catastrophic losses occur from the loss of lubricity and heat transfer, whereas chemical degradation of the parts reduces the life of the engine over the long term. It would be unusual for antiwear agents or corrosion inhibitors to be depleted without incursion of water and changes in viscosity. Many of the species responsible for chemical attack of the engine (e.g., water) also affect lubricity and are indirectly accounted for in that matter. For example, an oil that contains enough water to matter chemically will most likely also have changes in viscosity and surface tension.

Using the functions of motor oil and the associated properties, we can prioritize the properties with regards to criticality in Table 1. Occurrence is a statistical frequency derived from historical data, and OASIS should be able to provide those statistics. Probability is then inferred from statistics. Ease of measuring is based on current technology, and mirrors criticality in many ways because of the high demand for the ability to measure some properties.

List 1. Factors to consider in selecting properties for oil assessment in the field

1. **Ease**. What is easiest/cheapest to measure reliably (accurately, precisely) when using a portable device that does not rely on wet chemistry?
2. **Occurrence**. For what reason do most oil samples fail? How commonly is this failure encountered? What is the nature of the degradation? What is the frequency of a sample failing to meet the specifications for this particular property? What's the probability of a particular failure mode?
3. **Criticality**. What properties of oil are critical for proper engine health? More specifically, what types of oil degradation are apt to be associated with catastrophic engine loss rather than increased wear rates?

List 2. Critical functions of motor oil

1. **Lubricity** (surface tension, viscosity, antiwear additives, solid lubricants, lack of suspended solids (soot, wear debris, dust)
2. **Heat transfer** (surface tension, viscosity, heat capacity, thermal conductivity)
3. **Chemical protection** (acidity, basicity, contamination with water, coolant, fuel, corrosion inhibition)

Table 1. Characteristics of or contaminants in oil and their selection factors considered for portable oil assessment devices

Measurement	**Ease**	**Occurrence**	**Criticality**
Viscosity	★★★★★		★★★★★
Surface tension/contact angle§	★★★★		★★★★★
Flammability†	★★★		★★★★
Water/coolant contamination	★★★		★★★
Acidity	★★★		★★
Basicity	★★		★
Antiwear additives	★★		★★
Corrosion inhibitors	★★		★
Solids‡	★		★★
Density	★		★
Rheological modifiers	★		★
Detergents/dispersants	★		★
Thermal conductivity	★★★		★★★
Heat capacity	★		★★★

§ Surface tension, contact angle, and viscosity are linked due to the intermolecular forces responsible for both of them. Therefore, the ability to measure a change in one often implies the ability to measure a change in the other. Once one of these is measured, the need to measure the other independently declines. The interplay between cohesive and adhesive forces may be reasonably modeled using either surface tension (tensiometry) or contact angle (goniometry).

† Flammability may refer to fuel contamination measured by sniffer, gas chromatography, or other technique, or it may refer to flash point or similar test.

‡ Solids includes all wear debris, soot, sand, soil, or other insoluble matter, whether capable of passing through the filter or not. Filters should be sized to remove particulate matter large enough to adversely affect lubricity; this reduces criticality. Suspended solids can be measured via a particle counter, but this normally increases sample size. This is why ease has been rated at only one star for a portable device.

Device characteristics

Three sets of characteristics have been defined for the ideal portable oil assessment device: (i) measurement and assessment, (ii) connectivity and electronics, and (iii) portability, usability, and durability.

I. Measurement and assessment

1. Ability to quantitatively analyze oil for selected properties and/or constituents to generate number outputs for standard quantities (with generally accepted units) defined by ASTM, NIST, or other third party organizations (e.g., η, mPa s; water concentration, μg/g) with referee methods and TSC validation; no arbitrary numeric outputs

2. Ability to reduce outputs to a single summary decision, e.g., red/green, yes/no, change/ok

3. Straightforward applicability to commercial oils made by a variety of manufacturers

4. Capability to assess oils that are mixtures of different products

5. Capability to assess oils without comparison/contrast with a fresh reference sample of the oil

6. Capability to analyze all oils presently of interest to the Army, such as, but not limited to, L-23699, L-2104, H-5606, H-83282

7. Ruggedness in the matrix; invariance to formulation (i.e., unaffected by changes in corrosion inhibitor or antiwear agent, for example)

8. Self-test upon start-up (with internal calibration as needed)

9. External calibration on demand and performance check protocol for all functionalities on demand

II. Connectivity/electronic

1. Built-in RS-232 (EIA/TIA-232-E) and USB connections

2. Ability for data logging (minimum 500 samples) and subsequent plug and play for upload to laptop/PC via USB connection

3. Ability to upload to OASIS via RS-232 direct link (csv file) and via laptop/PC offline data management software

4. Self-contained operation, i.e., laptop or PC not required for routine use

5. Intuitive user interface with keyboard and USB ports for input

III. Portability, usability, and durability

1. External calibration and checks not required for routine use; no consumables required for routine use

2. Automatic power shut-off to conserve battery; constant-on switch when plugged in

3. Rechargeable battery

4. Able to sustain six-foot drop to hard surface (e.g., concrete) without injury

5. Light and small enough to be easily carried and set up by one person

6. Small sample volume (e.g., < 2 mL) and requiring minimal effort to obtain (e.g., dipstick residuum) if consumed; if measurement can be made in situ, then requirement is to avoid depleting oil from the sump (e.g., < 2 mL loss); insertion of device or collection of sample must require minimal time (e.g., 90 sec).

7. Minimal training requirements; essentially usable out of the box within 30 minutes

Oil assessment versus engine health assessment

Although the condition of the oil affects engine health, none of the quantities offered for measurement here reflect the engine condition. Consequently, it is proposed that wear debris analysis be incorporated at the time of oil change. Wear debris analysis is proposed through simultaneous rotrode atomic emission spectrometric analysis and filter debris analysis to be followed by an investigation into the corroboration of the results of the two techniques. This will ensure two condition-based maintenance components while still reducing the numbers of samples submitted for laboratory analysis and the results can be used to establish criteria for corrective and predictive maintenance (i.e., diagnosis and prognosis).

Final list of properties

Discussions with the Army OAP, as influenced by information from industrial sources, suggested that the list of properties be reduced to six: kinematic viscosity, total acid number, total base number, water concentration, ethylene glycol concentration, and soot content.

The TSC has proposed limits for parameters to be measured and requirements for data quality.

1. *Kinematic viscosity*
   expressed in $mm^2\ s^{-1}$

   Range: 50-250 $mm^2\ s^{-1}$;
   report also $\eta > 250\ mm^2\ s^{-1}$
   Error: ±10%, $50 < \eta \leq 75\ mm^2\ s^{-1}$
   ± 5%, $75 < \eta \leq 180\ mm^2\ s^{-1}$
   ± 20%, $\eta > 180\ mm^2\ s^{-1}$
   Trigger: $\eta < 105\ mm^2\ s^{-1}$ at ambient temperature (20-25 ˚C)

2. *Total acid number*
   expressed as mg KOH consumed/g oil

   Range: 0.0-5.0; report also TAN > 5.0
   Error: ± 0.5, 0.0 < TAN ≤ 2.0
   ± 1, TAN > 2.0
   Trigger: TAN > 1.0

3. *Total base number*
   expressed as mg KOH present/g oil

   Range: 0-16; report also TBN > 16.0
   Error: ±0.5, TBN ≤ 4.5
   ±1, 4.5 < TBN ≤ 12.0
   ±2, 12.0 < TBN ≤ 16.0
   Trigger: TBN < 4.0

4. *Water concentration*
   expressed in ppm

   Range: 0-5000 ppm
   report also $[H_2O] > 5000$ ppm
   Error: ±20 ppm, $0 < [H_2O] \leq 200$ ppm
   greater of ±50 ppm or ±10%, $200 < [H_2O] \leq 1000$ ppm
   ±20%, $[H_2O] > 1000$ ppm
   Trigger: $[H_2O] > 1200$ ppm

5. *Ethylene glycol*
   all antifreeze/coolant to be expressed as ppm ethylene glycol

   Range: 0-2500 ppm; report also [EG] > 2500 ppm
   Error: ±20 ppm, 0 < [EG] ≤200 ppm
   ±100 ppm, 200 < [EG] ≤1000 ppm
   ±10%, 1000 < [EG] ≤ 2500 ppm
   Trigger: [EG] > 900 ppm

6. *Soot (expressed in ppm)*

   Range: 0-5000 ppm; report also [soot] > 5000 ppm
   Error: ±100 ppm, 0 < [soot] ≤500 ppm
   ±200 ppm, 500 < [soot] ≤1000 ppm
   ±20%, 1000 < [soot] ≤ 5000 ppm
   Trigger: [soot] > 800 ppm

Error refers to the maximal deviation from the correct value that is permissible when taking into account all sources of error (imprecision, uncertainty, bias, and/or inaccuracy) for a single test by a single operator. Allowable errors were based on reasonable estimates of uncertainty and requirements for oil performance as a function of the value of the parameter as contrasted with high quality virgin oils.

Proposed triggers were developed using the HMMWV (Humvee) as a model, but realizing that there are varying requirements established by original equipment manufacturers. Aggregate data reported by TARDEC were used to construct a "one-size-fits-all" limit; nonetheless, it is possible and desirable to rely on individual OEM limits for each equipment or component type and lubricant type.

The primary influence of soot is to increase viscosity through the development of agglomerations of sludge. This is substantially prevented by detergency and dispersancy. In the initial planning document, Determinations of both kinematic viscosity and soot content go primarily towards impacts on lubricity; however, they also affect heat transfer by changing the rate at which the oil flows through the system.

Phases

1. Contact manufacturers with information about requirements and objectives and request a response (4 weeks).

2. Review manufacturer responses and select top submissions for further consideration (2 weeks).

3. Invite manufacturers to present their wares and to explain how they mesh with Army requirements. Provide manufacturers with a scoring sheet to be

used by TSC and AOAP. Allow 4 weeks for manufacturers to prepare their presentations.

4. Convene manufacturers to give one-hour presentations to demonstrate their equipment and its capabilities to AOAP and TSC staff. Evaluate equipment using scoring sheets.

Scoring sheet

The JOAP TSC prepared a scoring sheet for the combined evaluation by the Army OAP and the JOAP TSC staff. The scoring sheet was designed to objectify the process of evaluation as much as possible and to reduce the various kinds of information to a simple number score. Ideally, the scores will provide a straightforward mechanism for ranking the demonstrated devices and manufacturers.

It is anticipated that the top one or two devices and/or manufacturers will be offered the chance to engage in a cooperative research and development program with the U.S. Army and to work with the Joint Oil Analysis Program Technical Support Center.

This document should provide commercial vendors with sufficient information to determine if they have a competitive product and how that product is likely to be ranked against the Army's stated requirements.

Doc. no. JOAP-TSC-PD-U-05-04
Filename: Army-handheldflyer.wpd

Scoring sheet for hand-held/portable oil assessment devices and requirements for data quality

Device/manufacturer information

1. **(24) Does the manufacturer claim the device can assess all six properties and provide sufficient proof in the form of demonstrations and/or supporting documentation?**

   4 = demonstrated capability of direct measure and supporting documentation
   3 = either demonstrated capability or supporting documentation, but not both
   2 = inferred capability, indirect means of measure
   1 = undemonstrated, but claimed, capability (possibly after reconfiguring)
   0 = undemonstrated/unclaimed

   _________ TAN _________ TBN _________ Viscosity

   _________ Water _________ Coolant _________ Soot

1. _________ TOTAL

2. **(12) Does the device—as demonstrated—generate a numeric output for each parameter with physically real units that represent real quantities? If yes, award 2 points. If no, award 1 point if the manufacturer states that the device can be configured to do so. If no claim made, award no points.**

   2 = demonstrated numeric output of real physical quantity with defined units and traceability to a third party standard
   1 = demonstrated output of arbitrary unit, undemonstrated output of real quantity, but claimed capability to reconfigure to produce a defined physical quantity output
   0 = undemonstrated ability to produce arbitrary or real physical quantity output

   _________ TAN _________ TBN _________ Viscosity

   _________ Water _________ Coolant _________ Soot

2. _________ TOTAL

3. (6) Does the device reduce all the outputs to a single summary assessment that is intuitive and clear?

Y N 1. Is there a single decision indicator and summary assessment? If no, do not answer subparts 3.2 and 3.3.

Y N 2. If yes to 3.1, then is the indicator clear and intuitive to a casual observer?

Y N 3. If yes to 3.2, then is the indicator readily observable under a variety of conditions (low or bright light, noise, etc.)?

3. _________ TOTAL (each YES = 2 points; NO = zero)

4. (4) Does the device have a routine for internal calibration and/or self-test?

4 = demonstrated sufficient proof to examiners of both internal calibration and self-test
3 = demonstrated sufficient proof to examiners of one, and claimed capability for other
2 = demonstrated sufficient proof to examiners of one, does not have other
1 = claimed device can be reconfigured to have one or both
0 = undemonstrated/unclaimed for either

4. _________ SCORE

5. (4) Does the device have a means of externally calibrating all measurement functions?

4 = demonstrated proof of external calibration for all measurement types
3 = demonstrated proof of external calibration for some measurement types
2 = undemonstrated capabilities, but supportable claims for calibration of some/all
0 = undemonstrated/unclaimed

5. _________ SCORE

6. **(5) Does the device respond to all types of oil matrixes, including mixtures of same grade oils, without virgin samples for comparison/contrast based on demonstrated performance, supporting documentation, and/or sound scientific principles?**

Y N 1. Can the device readily move among commercial and/or military products of *different grades and different formulations* without reconfiguration or other significant action by the user?

Y N 2. Can the device reliably, accurately, and precisely test oils that are mixtures of different military products of the *same grade*?

Y N 3. Can the device reliably, accurately, and precisely test oils without a reference sample of virgin oil?

Y N 4. Did the manufacturer demonstrate the capability to reliably, accurately, and precisely test all of these oils of interest: L-23699, L-2104, H-5606, H-83282?

Y N 5. Did the manufacturer claim the capability to test L-23699, L-2104, H-5606, and H-83282 and provide supporting documentation?

6. __________ TOTAL (each YES = 3 points; NO = zero)

7. **(5) Did the manufacturer demonstrate or provide sufficient supporting documentation regarding the required connectivity and electronic characteristics of the ideal portable oil assessment device?**

Y N 1. Built-in RS-232 (EIA/TIA-232-E) and USB connections

Y N 2. Ability for data logging (minimum 500 samples) and subsequent plug and play for upload to laptop/PC via USB connection

Y N 3. Ability to upload to OASIS via RS-232 direct link (csv file) and via laptop/PC offline data management software

Y N 4. Self-contained operation, i.e., laptop/PC not required for routine use

Y N 5. Intuitive user interface with keyboard and USB ports for input

7. __________ SCORE (each YES = 1 point; NO = zero)

8. (7) Did the manufacturer demonstrate or provide supporting documentation regarding the portability, usability, and durability characteristics of the ideal portable oil assessment device?

Y N 1. External calibration and checks not required for routine use; no consumables required for routine use

Y N 2. Automatic power shut-off to conserve battery; always-on switch when plugged in

Y N 3. Rechargeable battery

Y N 4. Able to sustain six-foot drop to hard surface (e.g., concrete) without injury

Y N 5. Light and small enough to be easily carried and set up by one person

Y N 6. Small sample volume/consumption (e.g., < 2 mL) short sampling time (e.g., 90 sec).

Y N 7. Minimal training requirements; essentially usable out of the box within 30 minutes

8. _________ SCORE (each YES = 1 point; NO = zero)

____________ FINAL SCORE