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19th March 2021

CABARET V.3
BEARING ANALYSIS SOFTWARE SUB-LICENCE

You have expressed an interest in obtaining a free-of-charge sub-licence for the CABARET **Version 3** bearing analysis software. It is my pleasure to offer you this software which may be delivered for the use of sub-licencees in the form of a standalone Matlab executable application and a copy of its User Manual.

Before you accept this offer it is important that a number of points regarding the use of the software are understood and agreed prior to its despatch and use.

The Software

CABARET was developed under contract to the European Space Agency and so ESA can grant free sub-licences to organisations in the member states, for use in peaceful purposes within the field of space research and technology. In this instance, ESA has chosen to delegate the administrative aspects of granting these sub-licences to ESTL, a part of ESR Technology Ltd, on its behalf. This is the sub-licence that is offered to your organisation in this instance.

The software, under this free-of-charge ESA sub-licence, can only be used by your organisation within these parameters. A template sub-licence agreement can be found below. Please complete the below document by entering your organisational details, namely the company address and company name (in the editable fields), and completing the signature boxes at the bottom, then return a completed copy, signed on behalf of your organisation as a sub-licencee, to the undersigned. This can be in either hard copy, scanned or PDF electronic-signed format.

Upon receipt, we will verify that your organisation can qualify for the sub-licence and once confirmed, return the countersigned sub-licence agreement and provide access to the software and User Manual.

We can typically arrange this within approximately one week of receipt of the signed sub-licence agreement. This sub-licence is not valid for non-space use or for military applications or outside the member states of ESA for whatever purpose.

ESTL's Administrative Aspects

This software was developed by ESTL, a part of ESR Technology and as such, CABARET is owned by ESR Technology and is legally protected by copyright. The terms of this copyright and reference to this sub-licence are displayed on screen as you enter the CABARET program.

We would be pleased to offer you support in the form of training and maintenance of CABARET. For example, we can provide your organisation with a training package, tailored to your specific needs which would not only train your key staff on how to use the code, but could also provide guidance on how to interpret the results of CABARET. If this, or any other support in the use of CABARET is of interest to you, please do not hesitate to contact us. .

Points of Contact

If you require further information or any clarification regarding CABARET or its sub-licence, please do not hesitate to contact the following:

Regarding CABARET;
Dr Achilleas Vortselas
Telephone + 44 (0)1925 843401
e-mail: achilleas.vortselas@esrtechnology.com
Mr Simon Lewis
Telephone + 44 (0)1925 843451
e-mail: simon.lewis@esrtechnology.com

Regarding ESTL's administration of the awarding of ESA sub-licences;
Mr Chris Greenhalgh
Telephone + 44 (0) 1925 843487
e-mail: chris.greenhalgh@esrtechnology.com

Please contact ESA directly for any questions on the terms of the sub-licence.

We trust that the conditions applicable to use of the CABARET software by your organisation are clear and unambiguous and that you still want a copy of the software under these terms. In anticipation of your continued interest, we look forward to receiving your completed, signed sub-licence agreement.

Yours sincerely

Achilleas Vortselas
Research Engineer, ESR Technology Ltd
Direct line: +44 (0)1925 843401
e-mail: achilleas.vortselas@esrtechnology.com

To:

Company Name
Address Line 1
Address Line 2
Post Code
Country

ESTEC Software Sub-licence for CABARET v.3

Dear Sirs,

The EUROPEAN SPACE AGENCY (hereinafter referred to as “the Agency”) as licencee of the computer software defined and listed at Appendix 1 hereto, which has been developed as therein stated, grants Company Name as sub-licencee the use of this software under the following conditions, and as stated in Appendix 1. In this instance, the Agency has delegated the administrative aspects of granting these sub-licences to ESR Technology, on the Agency’s behalf.

1. The use of the program by the sub-licencee shall be limited to peaceful purposes within the field of space research and technology.

2. a) This sub-licence is granted free of charge.
   b) If support is requested, this shall be obtained via separate agreement from ESR Technology

3. The sub-licencee shall not make use of the software for any other purposes than stated above, and shall not grant further sub-licences, or disclose the software or any part thereof without the prior written consent of the Agency, both during and after the duration of the sub-licence, until such time as it falls into the public domain.

4. This sub-licence is non exclusive. The Agency and the owner of the program, ESR Technology, retain the right to grant other licences and sub-licences.

5. The sub-licencee shall not adapt or modify the software in any way without obtaining the Agency’s prior approval in writing. The Agency shall be entitled to use, transfer, and/or grant sub-licences of such modifications free of charge.

6. The Agency gives no undertaking as to the adequacy or suitability of the software for the proposed application and shall not be held liable for the consequences of it being so used.

7. The Agency shall not be held liable for any infringement of third party rights through the exercise of the sub-licence by the sub-licencee. The sub-licencee shall furthermore indemnify the Agency and ESR Technology from and against all claims, proceedings, damages, costs and expenses arising from the infringement of third party rights by the exercise of this sub-licence by the sub-licencee, or

from wrongful disclosure by the sub-licencee of the software, contrary to the terms of this sub-licence.

8. The sub-licence shall enter into force on the date of signature by the sub-licencee and shall remain in force for a period of five years thereafter. It may be extended by agreement in writing. It shall terminate immediately and automatically upon breach by the sub-licencee of the conditions stated in sections 1 and 3 above.

9. On termination of this agreement the sub-licencee shall either return all the software to the Agency, or shall certify to the Agency that they have destroyed the software and that there are no further copies in their possession.

10. This agreement is subject to the laws of The Netherlands.

11. This agreement is subject to arbitration in accordance with the provisions of clause 13 of the General Clauses and Conditions for ESA Contracts. Arbitration proceedings shall be held in The Hague.

12. If you find an error in the program during its utilisation, you are requested to inform the Agency as soon as possible.

Access to the software will be provided to qualifying sub-licencee organisations approximately 1 week from receipt by ESR Technology of a hard copy or electronic copy of this agreement, duly signed below on behalf of the sub-licencee to signify acceptance of its terms. ESR Technology will maintain a list of all CABARET sub-licencees and reserves the right to share this with the Agency upon request.

Please complete the sub-licencee column in the signature table below if willing to accept the above terms and return form to ESR Technology for review and counter-signature (we will forward you the completed sub-licnce in de course for your records).

	Sub-licencee	**ESR Technology Ltd.**
Signed on Behalf Of *(Insert Company name)*	Company Name	ESR Technology Ltd.
In *(Insert City, Country)*	Location	Warrington, U.K.
Date	Date	
Approved Signature		
Position In Organisation	Position	

Appendix 1

CABARET - Ball Bearing Analysis Software

CABARET v.3

CABARET is a bearing analysis code which is applicable to analysis of bearings operating at all speeds under general loading. Its use permits design and selection of bearings, materials and lubricants as well as prediction of bearing performance for a range of applications from low-speed mechanisms to high-speed turbopumps.

Development

CABARET was originally developed by ESTL, part of ESR Technology, under ESA contract no 8280/89/NL/FG and has since been maintained and extended under various ESA contracts, most recently 4000134269/21/NL/MG. Under the terms of these contracts companies or institutions within ESA member states are entitled to a free-of-charge sub-licence for use of Version 3 in the field of space research and technology, or space applications. CABARET can also be licensed by organisations outside the ESA member states, and for other applications.

Capabilities

CABARET integrates analyses for a number of features important in ball-bearing performance in a single code.

CABARET has been originally developed for bearing analysis tailored to the environment of a cryogenic rocket engine turbopump. This application is characterised by high bearing rotational speed, and heavy bearing loads, together with lubrication by thin solid films and cooling by the flow of liquid cryogen through the bearings.

CABARET v.3 retains in full the turbopump specific features, but now also permits a more generalised application of the same bearing analysis tools, by extending its applicability.

<u>User interface</u>
CABARET .v3 aims for ease-of-use, with a modern GUI and a 2D graphical representation of the bearing assembly. As a Matlab Standalone Application, it produces results compatible with Matlab for further analysis, however it does not require a Matlab license to operate.

<u>Quasi-Static Analysis</u>
The basis of CABARET is the so-called “quasistatic analysis” of bearing internal loads and motions. This enables the prediction of stiffness (or deflection) and contract stresses within single bearings or bearing pairs under generalised loading.

Coulombic Torque
This is the load-dependent torque primarily applicable to solid-lubricated ball bearings, but also relevant in liquid lubricated bearings under low speed conditions where viscous losses are negligible.

Fluid traction
For fluid-lubricated bearings, CABARET performs calculations of rolling and sliding resistance of the fluid at the contacts, allowing to extend torque calculations in to the mixed and EHL regimes. It also provides bearing-level torque estimations using the Palmgern-Harris and SKF empirical models.

Fluid Power Losses
For bearings immersed in fluid (e.g. LOX or LH2 in turbopump bearings), CABARET has the ability to estimate the fluid power losses based on empirical equations.

Flash Temperature
The localised “flash temperatures” generated at asperity contacts due to both microslip and skidding can also be estimated.

Thermal and Centrifugal Strain Effects
These modify bearing/shaft or housing fits and so the effective bearing preload. CABARET can predict both these changes and the resulting bearing torque.

Cage Motion
CABARET has a 3 degree of freedom cage motion simulation which enables qualitative assessment cage stability and indication of cage-ball and cage-land collision forces, in both solid- and fluid-lubricated bearings.

Fatigue Life
CABARET can estimate the fatigue life of bearings based on both the classical Lunberg-Plamgren method and the more recent SKF model which incorporates the effects of material properties and the sub-surface contact stress distribution.

Vibration Analysis
CABARET has a basic vibration analysis capability, which predicts the vibration frequency and forces generated by lobing of inner or outer races, together with the effects of variable compliance vibration.

Sensitivity Analysis
One of the most useful features of CABARET is the ability to carry out a sensitivity analysis. This feature allows designers to quickly generate curves which show the sensitivity of predicted output values to single input parameters (e.g. to predict the effects of variation of bearing conformity number on torque or deflection).

Libraries
CABARET v.3 includes libraries for Material and Fluid Properties, the latter extended with pressure- and temperature- dependend rheological properties. It also includes a new bearing library, which allows quick introduction of bearing manufacturer data into CABARET assemblies.

Accuracy

Direct comparisons, both with the predictions of other codes (SHABERTH and ADORE) and with experimental measurements, show excellent agreement for loads, deflections, forces, stiffness, Coulombic torque, flash temperature, vibration and fatigue.

In the case of torque estimation from fluid lubricated bearings, there is good agreement of CABARET predictions with experimental measurements and with the empirical equations, however users are advised that torque predictions have a wide margin of uncertainty, due to uncertainties in thermal and lubricant delivery conditions.

In the case of cage motion stability, friction, and wear, CABARET simulation results are in line with experimental observations and theoretical predictions but inherently more pessimistic. Also, by nature of the involved phenomena, quantitative comparisons are difficult; therefore users are advised to treat CABARET simulation results as indicative and not definitive proof of cage stability issues.

The data included in the Materials, Fluids, and Bearing Libraries are accurate enough for practical application to the best of our knowledge, however the users are required to verify or update them after consulting with their respective suppliers, since these details may change over time.