TOWARDS AN ENGINEERING STATION FOR PERFORMING SPACE-DEBRIS REMEDIATION BY MEANS OF HIGH-POWER LASER RADIATION – PLACEHOLDER PAPER!! THE FINAL WILL BE SUBMITTED ASAP...

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ABSTRACT

The number of resident space objects in Low Earth Orbit is rising steadily. The increase in the number of objects is showing an accelerated growth over the last decade, mostly due to the continuing installation of mega-constellations. As a consequence, the likelihood of collisions between defunct space debris objects and operational space assets is rising, too, resulting in a higher workload, an increase in associated costs for space operations (e.g. conjunction assessment, planning of collision avoidance maneuvers), and a reduction of mission lifetimes.

In the course of its Space Safety Programme (S2P), ESA has been focusing on the study and development of various technologies to address and mitigate the threat posed by the increased amount of resident space objects. The use of ground-based laser technology is making a significant contribution to this effort. Firstly, the use of pulsed lasers to accurately measure the ranges to space debris objects improves orbit determination and yielding smaller covariances. Secondly, high-power laser radiation (either pulsed or continuous wave) transmitted from the ground and through Earth's atmosphere could be used to change the orbit of a space debris object before a predicted high-risk conjunction with an operational space asset.

An ESA feasibility study performed by a DLR-led consortium showed that a more sustainable space environment could be achieved through the establishment of a global network of stations for space debris laser tracking and laser momentum transfer (LMT). In addition, a recent cost-benefit study conducted by NASA's Office of Technology, Policy and Strategy (OTPS) concluded that the deployment of ground-based lasers for debris remediation and just-in-time collision avoidance would produce net benefits in less than a decade. Many technical, operational, and regulatory challenges remain though, and need to be addressed and solved to further the development of LMT as a viable technology for space debris mitigation and remediation.

In this paper, we will present preliminary results from an ongoing ESA S2P activity (titled "Orbit Maintenance via Laser Momentum Transfer", OMLET) and done by a large DLR-led consortium. The OMLET project is performing a Phase A/B1 study for the development of a Laser Momentum Transfer Engineering Station. The Engineering Station, once built, will enable extensive testing and in-orbit demonstrations in preparation for a future operational laser-based collision avoidance system. In the subsequent phases of OMLET, the transition to operational services for precise ephemeris data provision and laser-based collision avoidance will be addressed.

Focus will be given to the consolidation of the functional and performance requirements of the Engineering Station system and their flow-down to subsystem level. A trade-off for different system architectures will be summarized and a baseline solution presented. Development needs for critical technology (e.g. laser sources, beam combination, AO correction of atmospheric effects) will be identified. Preliminary overview of work scope and schedule estimates for the future development of the Engineering Station will be provided. Finally, a preliminary concept of operations will be presented, taking into account legal and regulatory aspects as well as open issues in these

Proc. 9th European Conference on Space Debris, Bonn, Germany, 1–4 April 2025, published by the ESA Space Debris Office
Editors: S. Lemmens, T. Flohrer & F. Schmitz, (http://conference.sdo.esoc.esa.int, April 2025)

areas.

Keywords: Space debris; mitigation; collision avoidance; laser momentum transfer; ESA; Space Safety Programme; OMLET.

1. INTRODUCTION

The paper must be prepared in this two-column format and **should not exceed 15 pages**. This is a LaTeX 2_ε class based on the standard `article` class template to be followed.

It conforms to the specifications for ESA conference proceedings:

- standard A4 paper;
- two columns, they have 1 cm between them;
- 10 pt font, Times Roman;
- all titles in upper case

Compatibility with standard LaTeX is maintained as much as possible in order to simplify the transfer of text from or to another format. The only additional features are the `\keyword` command and the entry of authors and affiliations.

It replaces the LaTeX 2.09 style file that has been previously provided by the ESA.

For an excellent manual on using LaTeX, see Kopka & Daly, *A Guide to LaTeX*, 3rd ed., 1999, Addison Wesley Longman.

2. LASER MOMENTUM TRANSFER

2.1. Photon Pressure

2.2. Ablation

3. CONCEPT OF OPERATIONS

4. FUNCTIONAL BREAKDOWN AND SUBSYSTEMS

The class file is invoked with the `\documentclass` command, as
`\documentclass[a4paper,twocolumn]{spaceDebrisC}`
with option `a4paper`. The text will be centered on the specified paper type. The `twocolumn` option is to be given as the publication is to be in two columns per page.

4.1. Laser

4.2. Adaptive Optics

4.3. Telescope

4.4. Optical Search, Guidance and Monitoring

4.5. Station Infrastructure

4.6. Safety Systems

4.7. Control System

5. ALTERNATIVE DESIGN CONCEPTS, TRL ASSESSMENT AND TRADE-OFF

5.1. Photon Pressure

5.2. Ablation

5.3. Transportable LMT Transmitter

6. PRELIMINARY OPTICAL DESIGN FOR PHOTON-PRESSURE BASED LMT

6.1. Laser

6.2. Adaptive Optics

6.3. Telescope

6.4. Optical Search, Monitoring and Guidance

There are other (nearly) standard packages that should be included with the `\usepackage` command:

- `times` to use TimesRoman instead of Computer Modern (TeX) fonts ,
- `graphicx` for importing figures (see Section 9.1

The author may have his or her own extra packages, such as `amsmath` for advanced mathematical formatting.

A list of key words is to be printed below the abstract. They are entered *anywhere before the abstract environment* with the `\keywords` command.

```
\keywords{space; plasmas; electrons}
\begin{abstract}
. . .
\end{abstract}
```

Each author name should be entered with an `\author` command. Give the affiliation with the `\affil` command after all authors of the same affiliation. They will then be listed with a common footnote number.

```
\author{First C. Author}
\author{Second C. Author}
\affil{Author's Home Company, CA USA,
Email: \{FAuthor, SAuthor\}$@$companyX.xy}
\author{Last C. Author}
\affil{University of Somewhere,
 Email: LAuthor$@$university.so }
```

produces

First C. Author(1), Second C. Author(1), Last C. Author(2)
(1)Author's Home Company, CA USA,
Email: {FAuthor, SAuthor}@companyX.xy
(2)University of Somewhere,
Email: LAuthor@university.so

Except for the above features, the `spaceDebrisC` class is identical to the standard `article` class, as far as input is concerned. The document should be organized as usual.

```
\documentclass[a4paper,twocolumn]{spaceDebrisC}
% Any extra packages
\usepackage{times,natbib,graphicx,...}
% Title and authors
\title{Title text}
\author{First Author}...
\affil{First affiliation}
...
% Start of body
\begin{document}
\maketitle
% Keywords and abstract
\keywords{keyword1; keyword2; ... }
\begin{abstract}
Text of abstract
\end{abstract}
% Main text
\section{Heading}
Text
\subsection{Sub-heading}
Text
\section*{Acknowledgments}
Acknowledgment text
% Bibliography (Section 8)
\bibliographystyle{aa}
\bibliography{database name}
% Termination
\end{document}
```

Note: leave header and footer empty.

7. ABBREVIATIONS AND ACRONYMS

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Avoid using abbreviations in the title unless absolutely necessary.

8. BIBLIOGRAPHIC REFERENCES

Citations to bibliographic references are to be of the alphanum number style. The citations are parenthetical [3].

The list of references is placed at the end of the article in alphabetical order, as

```
\begin{thebibliography}{}
\bibitem{author73}
Author T., (1973). Astrophysical Quantities,
Athlone Press

\bibitem{nobody97}
Nobody B., Somebody G., Who D., et al., (1997).
 {\it The book}, Publisher, ed. 2

\bibitem{smith96}
Smith A., Jones B., (1996). The new discovery,
 {\it Other Journal}, {\bf 223}(1), 1029--1101
\end{thebibliography}
```

Note the empty braces after `\begin{thebibliography}`

9. LEGAL AND REGULATORY CHALLENGES

Figures and tables are inserted with the normal LaTeX environments `figure` and `table`. They are numbered automatically and one refers to the numbers with the `\label` and `\ref` system. Please note for non-vector formats: image resolution should be at least 600 dpi for monochrome and 300 dpi for colour images.

9.1. Preliminary Concept of Operations

The `figure` environment is used to enter a single column figure such as Figure 1, while `figure*` is for double column figures (Figure 2).

```
\begin{figure}
\centering
\includegraphics[width=0.8\linewidth]
{sample}
\caption{Sample figure showing how a
 eps(latex) pdf/png(pdflatex) graphic may
```

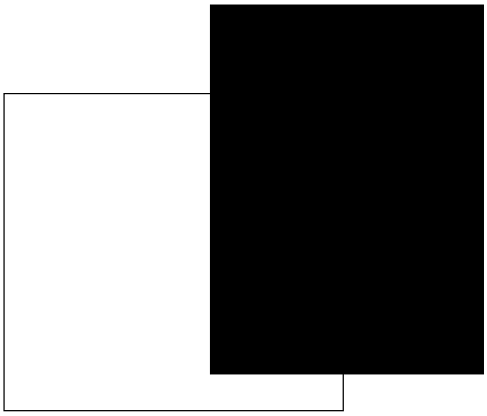

Figure 1. Sample figure showing how an pdf graphic may be included. This example is for a single column figure.

Table 1. A sample table illustrating usage of the LaTeX table environment.

First column	Col. 2	Col. 3	V mag
row 1	11.0	25.0	12
row 2	11.0	25.0	12
row 3	11.0	25.0	12
row 4	11.0	25.0	12
row 5	11.0	25.0	12

```
 be included.
This example is for a single column
figure.\label{fig:single}}
\end{figure}
```

One can then refer to this figure with `Figure~\ref{fig:single}`, producing “Figure 1”.

The `\includegraphics` command is made available with the `graphicx` package and allows the importation of graphic files. For PostScript output (with the `dvips` program) these graphics must adhere to the *encapsulated* PostScript standard.

The same syntax can also be used with pdfTeX, a variant on the TeX program producing PDF output directly. In this case, the figures must be in PDF, PNG, or JPEG format. It is not necessary to include the extension in the file name (`file=sample` suffices), something that makes the LaTeX text more general for both normal TeX and pdfTeX. (It may however be necessary to add the option `[pdftex]` when loading the graphics packages.)

9.2. Outline of a Legal Framework

Tables are placed and numbered and referred to with the `table` and `table*` environments. The contents of the table are normally entered with the `tabular` or `tabbing` environments. The `\caption` now comes at the top of the table, before the table contents.

10. SUMMARY AND OUTLOOK

Formulae which appear in the running text should be enclosed in `$` signs. For example, to produce the equation $a^2 + b^2 = c^2$ within a paragraph type `$a^2 + b^2 = c^2$`. Displayed formulae are produced using the `\begin{equation}` and `\end{equation}` commands (see Equation 1). This produces equations which are automatically numbered sequentially throughout your paper. Equations which should appear together can be formatted using `\begin{eqnarray}` and `\end{eqnarray}` as for Equations 2 and 3:

$$\Delta\hat{a}_i = \sum_j \frac{\partial f_i}{\partial a_j} \Delta a_j \tag{1}$$

$$\alpha = \alpha_0 + (T - T_0)\,\mu_{\alpha*0} \sec\delta_0 \tag{2}$$

$$\delta = \delta_0 + (T - T_0)\,\mu_{\delta 0} \tag{3}$$

When in math mode (i.e. within the `equation` or `eqnarray` environment) all letters appear in italics. However, the preferred notation is for subscripts, superscripts[1] and text within the equation to be typeset as roman. To achieve this use the `{\mbox{..}}` command. Thus, `$T_{\mbox{eff}}=5.8\times10^{3}$~K` produces $T_{\mathrm{eff}} = 5.8 \times 10^3$ K. Note that units should be tied to the numerical value using ~ and should always be in roman font (the default outside of math mode).

ACKNOWLEDGMENTS

The work described in this paper is being performed in the framework of the ESA S2P activity ”S2-LT-02 Phase A/B1 Orbit Maintenance via Laser Momentum Transfer (OMLET)” under ESA Contract No. 4000145666/24/D/MRP. Financial contributions by Germany, Norway, Switzerland, Austria, and the Czech Republic are kindly acknowledged.

REFERENCES

1. Author T., (1973). Astrophysical Quantities, Athlone Press

[1] Except when the superscript or subscript are variables.

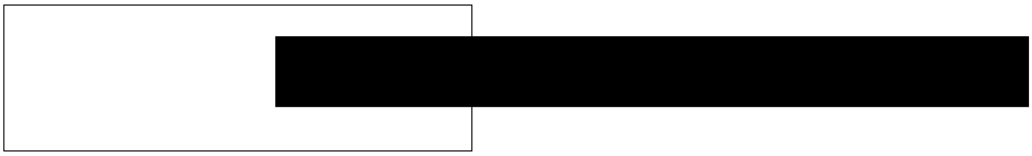

Figure 2. Sample figure showing how an encapsulated PostScript graphic may be included. This example is for a double column figure, which does cause more placement problems than single column ones.

2. Nobody B., Somebody G., Who D., et al., (1997). *The book*, Publisher, ed. 2

3. Smith A., Jones B., (1996). The new discovery, *Other Journal*, **223**(1), 1029–1101