LUMEN Demonstrator Project Overview

By Jan DEEKEN,[1)] Michael OSCHWALD,[1)] and Stefan SCHLECHTRIEM[1)]

[1)]*Institute of Space Propulsion, DLR, Hardthausen, Germany*

(Received June 21st, 2019)

In recent years the scientific focus of the DLR Institute of Space Propulsion was placed on experiments related to rocket engine combustion phenomena and thrust chamber aspects. A natural extension of this scientific portfolio is the step towards engine level competence by joining the existing component level competences. The DLR project LUMEN (liquid upper stage demonstrator engine) aims at developing and operating a modular LOX/LNG bread-board engine in the 25 kN thrust class for operation at the new P8.3 test facility in Lampoldshausen. This article discusses the background of the LUMEN project, its scientific goals and the means to achieve them. The planned bread-board engine is described and the reasoning behind propellant selection, choice of the expander-bleed scheme as the engine cycle layout and selection of technologies for key engine components is explained. This includes the API injector technology for increased combustion performance and heat exchange, a battleship turbomachinery setup and a hybrid ceramic nozzle extension design. The project logic, project timeline as well as recent advances and milestones are illustrated.

Key Words: LUMEN, engine demonstrator, LOX/LNG

Nomenclature

A	:	area, m^2
a	:	angle, rad
B	:	block
b	:	base length, m
C	:	Cross section
c	:	coefficient
c_a	:	coefficient for parameter a
c_b	:	coefficient for parameter b
V	:	velocity, m/s
X	:	position
α	:	angle of attack, rad
β	:	sideslip angle, rad
θ	:	pitch angle, rad
ϕ	:	roll angle, rad
τ	:	torque, Nm
Subscripts		
0	:	initial
f	:	final

1. Background and motivation

DLRs Institute of Space Propulsion has a long standing heritage of experimental work related to aspects of rocket engine thrust chamber design. Due to Europes traditional focus on LOX/hydrogen propulsion systems, such as Vulcain, HM-7B or Vinci, DLRs scientific focus was also placed on high pressure combustion of LOX and hydrogen. The scientific fields of interest included topics such as:

- Ignition and transients
- Combustion efficiency and dynamics
- Combustion chamber cooling
- Nozzle flow
- Thrust chamber structures

Experiments related to high pressure combustion were conducted with a wide variety of test specimen at the European research and development test bench P8, which offers the possibility to test at conditions representative of typical rocket engines.[4)] Since 2014, DLR is also building up competences in the field of turbomachinery.

In 2017, the LUMEN breadboard engine project was initiated by DLR with the following main goals:

- Advancing the understanding of engine processes at a system level
- Demonstrating the ability to predict the behavior of whole engine cycles
- Linking of competences in engine component design existing at DLR
- Advancing the organizational ability to conduct engine demonstrator projects in a research focused environment
- Providing a modular test bed for investigations of new components and engine cycle layouts in later project stages

[12)]

2. LUMEN Demonstrator definition

3. Selected component technologies

4. Project timeline and development status

5. Outlook

6. Introduction

These guidelines include complete descriptions of the fonts, spacing, and related information for producing your manuscripts. Please pay extreme attention to keep the original format shown in this file. Authors using LaTeX may use the TJSASS class file and sample manuscript (this file) provided by JSASS. But it should be noted that the document should be

Table 1. Form of the paper.

Items	Values
Paper size	A4
Max number of pages	10
Margin	Top: 25 mm and under: 25 mm side: 17 mm
Font	Times-New-Roman and symbol

submitted in PDF format, and that no support for this sample manuscript and the class file is provided by JSASS. When making a pdf file, all the fonts including the standard PostScript fonts (such as Times and Symbol) must be embedded in the document, and don't use national (e.g. Japanese) fonts.

All manuscripts are to be submitted electronically via the ISTS Web site at

`http://www.ists.or.jp/paper.html`

no later than the deadline designated in the ISTS Web page.

7. Formatting Your Paper

Each paper is allowed up to 10 pages of texts, including figures and tables. But never exceed 10 pages. Color graphics are acceptable. However, movie files and some kinds of software tools should not be included in the paper.

Papers with less than 6 pages will be automatically categorized into "Research note", and papers presented in u-session of ISTS will be categorized into "Educational program report" no matter how many pages when they are accepted for publication in Trans. of JSASS Aerospace Technology Japan.

The authors whose papers are not related to technologies but science are encouraged to submit their manuscript to Transactions of JSASS, but not Aerospace Technology Japan, because Aerospace Technology Japan is a journal featuring the field of aerospace technologies specifically.

Table 1 shows the form of the paper. The authors need not put the notice of your paper number and the copyright on their manuscripts. It will be put on the papers by the publisher.

8. Title etc.

8.1. Title

The title should be brief and concise. The title should be centered, and in Times 14-point, boldface type. Capitalize the first letter of nouns, pronouns, verbs, adjectives, and adverbs; do not capitalize articles, coordinate conjunctions, or prepositions (unless the title begins with such a word). Leave a blank line after the title. The space between the lines is 17.5 point.

8.2. Author name(s) and affiliation(s)

Author names are to be centered beneath the title, printed in Times, and non-boldface type. The full name must be typed. Only primary contributors should be listed in authors list; others may appear in Acknowledgment. The first name is printed in 10 pt, and the first letter of the first name should be capitalized. The family name must be capitalized, only the first letter of the family name is 10 pt, and the other letters of the family name must be in 8pt. "and" is also necessary before the last author's name. For the case of more than two authors, a command is necessary between author's names.

Place a superscript number corresponding to the affiliation on right of each author's name, but after a comma between authors' names.

Affiliations should follow on the next line, be centered, italicized and in Times 8-point, not bold. City name must be included, but **prefecture (state, specified districts) name must be excluded**. Leave two blank lines after the affiliations. The space between the lines is 10-point. Affiliation number with a parenthesis must be placed in front of each affiliation in Roman.

8.3. Received date

"(Received date Month day, 2019)" is unnecessary when submitting your manuscript for proceedings, but it is necessary above Abstract when submitting to "Aerospace Technology Japan." The received date is the first date of submission to "Aerospace Technology Japan."

8.4. Abstract

Abstract should be indented 4 letters, 100- to 200-words, written as a single paragraph and printed in Times 8.5-point, not bold, flush left. Leave 30 mm in both sides. The space between the lines is 11.5-point.

It should be a summary and complete in itself. The abstract should indicate the subjects dealt with in the paper and should state the objectives of the investigation. New findings and conclusions of the experiment or argument discussed in the paper must be stated in the abstract.

Leave one blank line after the abstract.

8.5. Key words

Key word should be centered, in Times 8.5-point, not bold. Begin by "**Key Words:** " (in Times 8.5-points, boldface type, and 2 letters blank) at the top. No more than 5 key words. All words must start with upper case.

9. Main Text

Type your main text in 9.5-point Times, single-spaced. All paragraphs should be indented 2 letters. Be sure your text is fully justified. The space between the lines is 12-point.

9.1. Nomenclature

A nomenclature section is required for papers containing more than a few symbols; nomenclature definitions should not appear in the text. Nomenclature should be beneath the key words as follows; "Symbol (V, X etc.) - : (colon) - (2 letter blank) - Definitions". The position of colon is 35 mm from the left end of the page. Please use standard symbols whenever possible. The symbols are in 9.5-point and the definitions are in Times 9.5-point, not bold. The symbols must be listed in alphabetic order such as "A, a, B, b." Greek symbols must be listed in Greek alphabetical order after English alphabet. All symbols need to be defined. All abbreviations need to be spelled out at the first instance.

9.2. Introduction

The paper must include an Introduction - a brief assessment of prior work by others and an explanation of how the paper contributes to the field.

9.3. Major-headings

For example, "**1.**(2 letters blank)**Introduction**", should be Times 9.5-point boldface, with the first letter capitalized, flush left, with one line blank from last, leaving one blank line to next. Use a period (" . ") after the heading number, not a colon.

9.4. Sub-headings

For example, "**4.4.**(2 letters blank) **Second-order headings**", should be Times 9.5-point boldface, initially capitalized, flush left and with no line blank from last.

9.4.1. Subsub-headings

For example, "**4.4.1.**(2 letters blank) **Third-order headings**", should be Times 9.5-point boldface, initially capitalized, flush left and with no line blank from last.

9.5. Figures

Figure captions should be 8-point Times and centered. For example: "Fig.(a blank)1.(2 blanks)The symbol of JSASS." Capitalize only the first word of each caption. Figure captions must end with a period. The captions are to be below the figures. Please use "Figure 1" or "Figures 1 and 2" at the beginning of sentences. Otherwise, use "Fig. 1", or "Figs. 1 and 2" in the text. All figures must be referred to in the text.

9.6. Tables

Table captions should be 8-point Times and centered. For example: "Table(a blank)1.(2 blanks)Form of the paper." Capitalize only the first word of each caption. Table captions must stop with a period. The captions are to be over the tables. All tables must be referred to in the text. The horizontal top and bottom lines must be bold. Vertical lines should not be used unless it is difficult to distinguish columns.

9.7. Equations

The symbols should be in 9.5-point and centered. The equation numbers should be right flush as

$$A + B = C, \tag{1}$$

and

$$D + E = F. \tag{2}$$

Please use "Equation (1)" or "Equations (1) and (2)" at the beginning of sentences. Otherwise, use "Eq. (1)", or "Eqs. (1) and (2)" in the text.

Other example equations are shown in the following. One is the definition of St_n

$$St_n = \frac{f_n L}{U_\infty} = \frac{n}{\left[\beta M_\infty \cdot \left(1 + \frac{\gamma - 1}{2} M_\infty{}^2\right)^{-1/2} + \frac{1}{K}\right]} \qquad n = 1, 2, 3, \cdots \tag{3}$$

and another one is differential equation

$$\left\langle \nabla^2 \phi \right\rangle_i = \frac{2d}{\lambda n^0} \sum_{j \neq i} \left[\left(\phi_j - \phi_i\right) w\left(\left|\mathbf{r}_j - \mathbf{r}_i\right|\right) \right], \tag{4}$$

where

$$\lambda = \frac{\sum_{j \neq i} \left|\mathbf{r}_j - \mathbf{r}_i\right|^2 w\left(\left|\mathbf{r}_j - \mathbf{r}_i\right|\right)}{\sum_{j \neq i} w\left(\left|\mathbf{r}_j - \mathbf{r}_i\right|\right)}. \tag{5}$$

A comma is necessary after each equation if equations are not the last sentence. If the equation is the last sentence, a period is necessary after the equation.

Fig. 1. The symbol of JSASS. Only the first letter in a sentence should be upper case. **Single-line caption should be centered. In plural-line caption, lines before the last one both sided, the last one flush left. Captions must stop with a period.**

10. Others

Formats for references and acknowledgments should fit to the followings: For references, list and number all bibliographical references in 8-point Times at the end of your paper. The space between the lines is 10-10.5-point. When references are cited in the text, write the numbers referred to as A,[1)] or B,[2,3)] or C,[5–11)] after a comma,[?)] or a period.[14–24)] If the numbered reference citation is a word of the main text, write it as in the following examples. "Reference 25) gives the definition of ....." at the beginning of sentence, or "As shown in Ref. 26), the three-body problem should be taken into account for mission design." for other cases.

The sample of references is shown at the end of this guideline. DOI is unnecessary for references. The heading of it is "**References**" that is 9.5-point, bold, centered. All references must be referred to in the text.[27,28)]

The heading "**Acknowledgments**" is 9.5-point, bold, flush left.

11. PDF file conversion

- Use of Adobe: Acrobat Distiller and a version 1.5 (Acrobat 6.0) PDF file are recommended.
- Set the resolution to 600dpi or similar.
- The size of a pdf file must be less than 5MB per each paper.
- Embed all fonts (symbols, space etc.) in the PDF file.
- Do NOT create bookmarks.
- Do NOT set security.

12. How to use tjsass.cls

To use the tjsass class, installation of some packages is required. Please check RequiredPackages in the sample file.

To prepare a draft for the conference or journal, please use one of the following commands.

```
\documentclass[TJSASS]{tjsass} % Trans. JSASS
\documentclass[ATJ]{tjsass} % Aero. Tech. Japan
```

```
% year of publication
\pubyear{2020}
% volume number
\bookvolume{18}
% issue number
\bookissue{1}
% starting page number
\setcounter{page}{1}
% submission date
\receiveddate{June 21st, 2019}
```

```
% revision date in case of Trans.
\revisiondate{August 10th, 2019}
%acceptance date in case of Trans.
\acceptеddate{September, 20th, 2019}
%conference information in case of APISAT
\confinfo{presented at APISAT 2016}
% paper title
\title{Title}
% paper subtitle only when necessary
\subtitle{sub title}
%author name
\author{\NAME{Ichiro}{Koku}\thanksNum{1}}
\CorresAuthor{koku@jsass.org}
% affiliation
\thanksOrg{affiliation}

\begin{abstract}
write abstract here
\end{abstract}
\keywords{Key word}

\begin{document}
\maketitle
write text here
\end{document}
```

13. Conclusion

Conclusion should be clearly stated.

Acknowledgments

The editorial office appreciates authors' efforts to fully follow this template style when submitting the manuscript to Aerospace Technology Japan because the editorial office does not provide a type-setting service.

References

Book case)

1) Batchelor, G. K.: *An Introduction to Fluid Dynamics*, Cambridge University Press, London, 1967, pp. 1–10.
2) Arakawa, Y., Kuninaka, H., Nakayama, N., and Nishiyama, K.: *Ion Engines for Powered Flight in Space*, Corona Publishing, Tokyo, 2006, pp. 18–20 (in Japanese).
3) Goto, N. and Kawakita, T.: Bifurcation Analysis for the Inertial Coupling Problem of a Reentry Vehicle, *Advances in Dynamics and Control, Sivasundaram, S. (ed.)*, Chapman & Hall, New York, 2004, pp. 45–55.

Journal paper case)

4) Koschel, W. and Haidn, O.: P8 - The new French/German Test Facility for H_2/O_2 High Pressure Rocket Engine Combustion Research, *International Journal of Hydrogen Energy*, **23** (1998), pp. 683694.
5) Hainds, F. D. and Keyes, J. W.: Shock Interference in Hypersonic Flows, *AIAA J.*, **10** (1972), pp. 1441–1447.
6) Miyaji, K., Tsurumaki, A., and Tsukada, H.: On Accuracy of Prediction of Flutter Boundaries on Unstructured Grids, *Trans. Jpn. Soc. Aeronaut. Space Sci.*, **47** (2004), pp. 195–201.
7) Atobe, S., Kuno, S., Hu, N., and Fukunaga, H.: Identification of Impact Force on Stiffened Composite Panels, *Trans. JSASS Aerospace Technology Japan*, **7**, ists26 (2009), pp. Pc_1–Pc_5.
8) Shimizu, E., Isogai, K., and Obayashi, S.: Multi-Objective Design Study of a Flapping Wing Power Generator, *J. Fluids Eng.*, **130** (2008), pp. 021104-1-021104-8.
9) Kojima, H., Furukawa, Y., and Trivailo, P. M.: Experimental Study on Delayed Feedback Control for Libration of Tethered Satellite System, *J. Guid., Control Dynam.*, **35** (2012), pp. 998–1002.
10) Wilde, K., Gardoni, P., and Fujino, Y.: Seismic Response of Base-isolated Structures with Shape Memory Alloy Damping Devices, *Proc. SPIE*, **3043** (1997), pp. 122–133.
11) Hara, S., Matsunaga, T., Nakamura, J., Horibe, T., and Makino, D.: Quantitative Stability Evaluation Based on Region of Attraction for Control Method Choice for Nonlinear Systems and Its UAV Application, *Japan Soci. Aero. Space Sci.*, **65** (2017), pp. 251–257 (in Japanese).

Conference paper case)

12) Hoffmann, D., Froehlke, K., and Bruemmer, G.: Low Pressure Test Cell P8.3 for Test Facility P8 at DLR Lampoldshausen, 2nd Ground-Based Space Facilities Symposium, Toulouse, France, 2017.
13) Deeken, J., Suslov, D., Rackemann, N. and Preuss, A.: Combustion Performance and Stability of a Porous Injector Compared with a State-of-the-Art Coaxial Injector, Space Propulsion 2014, Cologne, Germany, 2014.
14) Tamakoshi, D. and Kojima, H.: Interplanetary Low-thrust Trajectory Using Earth Gravity Assist and Invariant Manifold Technique, 68th International Astronautical Congress, Adelaide, Australia, IAC-17,C1,8,4,x37086, 2017.
15) Trivailo, P. M. and Kojima, H.: Simulation of Space Nets with Nonlinear Material Behaviour, Capturing Space Debris, 31st International Symposium on Space Technology and Science, Matsuyama, Japan, 2017-r-67p, 2017.
16) Murayama, M., Nakahashi, K., and Matsushima, K.: Unstructured Dynamic Mesh for Large Movement and Deformation, AIAA Paper 2002-0122, 2002.
17) Fujii, A. H., Watanabe, T., Sahara, H., Kojima, H., Takehara, S., Yamagiwa, Y., et al.: Space Demonstration of Bare Electrodynamics Tape-Tether Technology on the Sounding Rocket S520-25, AIAA Paper 2011-06503, 2011.
18) Kojima, H., Yoshimura, Y., and Taniguchi, C.: Study on CMG-Manipulator Cooperative Control for Space Robot Equipped with CMG, Proceeding of 61st Space Sciences and Technology Conference, Niigata, Japan, JSASS-2017-4001, 2017 (in Japanese).

Technical report case)

19) Williams, G. J., Domonkos, M. T., and Chavez, J. M.: Measurement of Doubly Charged Ions in Ion Thruster Plumes, NASA TM-2002-211295, 2002.
20) Nakai, E.: Transonic/Supersonic Flutter Characteristics of a Cantilevered Low-aspect Ratio Swept Wing, NAL TR-288, 1972 (in Japanese).
21) Usui, M. and Kuninaka, H.: Characteristics of Ion Grid System, JAXA-SP-06-019, 2007, pp. 28-31 (in Japanese).
22) Machida, K. and Miyaji, K.: 3D Wing Flutter Analysis by Bending-Torsion Beam Model and Unstructured CFD, JAXA-SP-05-017, 2006, pp. 94–99 (in Japanese).

Dissertation case)

23) Roberts, J. A.: Satellite Formation Flying for an Interferometry Mission, Ph.D. Thesis, Cranfield University, 2005.
24) Kato, H.: Prediction of Wake Turbulence Behaviors Using Weather Observation and Simulation, Master's Thesis, Tohoku University, 2010 (in Japanese).

Web source case)

25) Bush, G. W.: The Vision for Space Exploration, NASA Headquarters, 2004, http://www.nasa.gov, (accessed October 12, 2016).
26) Koon, W. S., Lo, M. W., Marsden, J. E., and Ross, S. D.: Dynamical Systems, the Three-Body Problem and Space Mission Design, Marsden Books, 2008, http://www2.esm.vt.edu/˜sdross/books/ (accessed Septemer 23, 2016).
27) Global Land Cover Characterization, http://edc2.usgs.gov/glcc/glcc.php (accessed July 2, 2012).
28) Geospatial Information Authority of Japan, http://www.gsi.go.jp/kiban/ (in Japanese) (accessed August 2, 2012).