	EUROPEAN COMMISSION RESEARCH AND INNOVATION DG	Periodic Report

Project No: 262733

Project Acronym: ESAIL

Project Full Name: Electric sail propulsion technology

Periodic Report

Period covered: from 01/12/2010 **to** 30/11/2011

Start date of project: 01/12/2010

Project coordinator name:
Dr. Pekka Janhunen

Project coordinator organisation name:
ILMATIETEEN LAITOS

Date of preparation: 08/12/2011

Date of submission (SESAM):

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Periodic Report

PROJECT PERIODIC REPORT

Grant Agreement number:	262733
Project acronym:	ESAIL
Project title:	Electric sail propulsion technology
Funding Scheme:	FP7-CP
Date of latest version of Annex I against which the assessment will be made:	06/12/2010
Period number:	1st
Period covered - start date:	01/12/2010
Period covered - end date:	30/11/2011
Name of the scientific representative of the project's coordinator and organisation:	Dr. Pekka Janhunen ILMATIETEEN LAITOS
Tel:	+358 9 1929 4635
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E-mail:	Jaana.palmunoksa@fmi.fi
Project website address:	https://www.electric-sailing.fi/fp7s (login esailfp7)

Declaration by the scientific representative of the project coordinator (1)

I, Dr. Pekka Janhunen ILMATIETEEN LAITOS , as scientific representative of the coordinator of the project ESAIL and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

The project has fully achieved its objectives and technical goals for the period.

The attached periodic report represents an accurate description of the work carried out in this project for this reporting period.

The public website is up to date.

To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 6) and if applicable with the certificate on financial statement.

All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 5 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name	Dr. Pekka Janhunen ILMATIETEEN LAITOS
Date	

This declaration was visaed electronically byPekka JANHUNEN(ECAS user name njanhupe) on

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1. Publishable summary

Summary description of project context and objectives

The Electric Solar Wind Sail (E-sail) is a recent invention of ultra-efficient propellantless in-space propulsion technology. It uses the solar wind charged ions as natural source for producing spacecraft thrust. The E-sail is composed of a set of long, thin, conducting and positively charged tethers which are centrifugally stretched from the main spacecraft and kept electrically charged by an onboard electron gun powered by solar panels.

The E-sail concept is an enabling technology for reducing significantly the time, cost and mass required for spacecraft to reach their destinations. It has been estimated that it has the potential to improve the state of the art of propulsion systems by 2 to 3 orders of magnitude if using the lifetime-integrated total impulse versus propulsion system mass as the figure of merit. Furthermore, the E-sail propulsion technology is truly a green propellantless method reducing significantly the mission launch masses and the amount of chemical propellant burnt in the atmosphere. As an electromechanical device it does not need any poisonous, explosive or radioactive substances or dangerous construction procedures.

In the ESAIL project we develop the key E-sail technologies (tethers, tether reels, spinup and guidance/control method based on gas and FEEP thrusters) to prototype level. The goal is that after the project, the decision to build and fly the first E-sail demonstration mission in the solar wind can be made. As a secondary technological goal, the project will raise the FEEP and gas thruster readiness level for general-purpose satellite attitude control purposes.

Description of work performed and main results

The ESAIL project is mostly a TRL 4-5 prototyping and hardware development activity. In all important respects, we are fully on schedule and have met or exceeded the expectations:

An automatic ultrasonic tether bonding factory has been designed and built. The factory runs without user intervention and produces 2-wire or 4-wire E-sail tether,
currently at a rate of about 10 seconds per bond. The factory has been used to produce altogether 250 m of 2-wire tether and 23 m of 4-wire tether. The longest contiguous 2-wire (4-wire) tether was 110 (11) m.
We are very well on track for being able to produce 1 km 4-wire tether at the end of the project, which was the officially stated goal.

A CAD design of the Remote Unit (small autonomous device sitting on tip of each main tether) and its subsystems was very nearly completed.
We adopted 0.9-4 AU as the required operational solar distance range for the Remote Unit, which will allow a broad range of E-sail missions with
the prototyped Remote Unit design, including near-Earth missions, asteroid missions and outer solar system missions.
At the end of the project we should have a TRL 4-5 prototype of the unit, preferably with less than 500 g mass. We are on track towards that.

A miniature butane cold gas thruster suitable for the Remote Unit has been designed, to be flight-tested on the QB-50 CubeSat mission.

A miniature ionic liquid FEEP thruster for the Remote Unit was successfully built and tested in a vacuum chamber, and the plasma plume angular characteristics were measured.

Multiple reel in/reel out cycles of 10 m 2-wire Heytether were successfully demonstrated without breaking any bonds of the tether.

A preliminary version of a dynamic mechanical simulator software exists now.

Expected final results and potential impacts

The main goal is to demonstrate TRL 4-5 prototypes of the key components of the electric sail, scalable to 1 N thrust with 100-200 kg propulsion system mass and 0.9-4 AU operational solar distance range.
Specifically, this includes building and testing a laboratory prototype of the Remote Unit and its components (butane gas thruster, ionic liquid FEEP thruster, motorised auxtether reels, etc.) and producing at least 1 km of qualify-controlled
final-type 4-wire Heytether made of 25/50 um aluminium wire.

If we succeed, it means that the door is open to a novel, general-purpose breakthrough method of moving in the solar system without consuming propellant.
The next step after that must be a solar wind test mission for flight validation. The outcome could be enormous, for it has the potential to literally open up the solar system's
scientific and economic treasures in a way which was not even dreamt about only five years ago.

Project public website address:	http://www.electric-sailing.fi/fp7

2. Core of the report

Project objectives, Work progress and achievements, and project management during the period

The Project Summary Pdf document contains the core of the report.

3. Deliverables and milestones tables

Deliverables (excluding the periodic and final reports)

Del. no.	Deliverable name	Version	WP no.	Lead beneficiary	Nature	Dissemination level	Delivery date from Annex I (proj month)	Actual / Forecast delivery date	Status	Comments
1	Project management guidel ines	1.0	10	ILMATIETEEN LAITOS	Report	PU	0	17/03/2011	Submitted	
2	Periodic report	0.0	10	ILMATIETEEN LAITOS	Report	PU	11	01/11/2011	Not submitted	
3	Periodic report	0.0	10	ILMATIETEEN LAITOS	Report	PU	23	01/11/2012	Not submitted	
4	Periodic report	0.0	10	ILMATIETEEN LAITOS	Report	PU	35	01/11/2013	Not submitted	
5	Final report	0.0	10	ILMATIETEEN LAITOS	Report	PU	35	01/11/2013	Not submitted	
1	Tether factory (100 m) de sign and implementation a nd 100 m tether productio n	0.0	21	HELSINGIN YLIOPISTO	Report	PU	13	01/01/2012	Not submitted	
2	Tether factory (1 km) req uirements	0.0	21	HELSINGIN YLIOPISTO	Report	PU	17	01/05/2012	Not submitted	
3	Tether factory (1 km) des ign and implementation an d 1 km tether production	0.0	21	HELSINGIN YLIOPISTO	Report	PU	31	01/07/2013	Not submitted	
1	Tether coating report	0.0	22	ILMATIETEEN LAITOS	Report	PU	16	01/04/2012	Not submitted	
1	Tether space environment requirements	1.0	23	ILMATIETEEN LAITOS	Report	PU	7	17/08/2011	Submitted	
2	Tether vacuum-testing set up	1.0	23	ILMATIETEEN LAITOS	Report	PU	11	07/11/2011	Submitted	
3	Tether vacuum-testing res ults	0.0	23	ILMATIETEEN LAITOS	Report	PU	25	01/01/2013	Not submitted	
1	Auxiliary tether report	0.0	24	ILMATIETEEN LAITOS	Report	PU	6	01/06/2011	Not submitted	

1	Requirements specificatio ns of the tether reeling tests	1.0	31	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	5	01/06/2011	Submitted	
2	Reeling tests plan	1.0	31	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	5	01/06/2011	Submitted	
3	Reeling test results	1.0	31	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	5	23/06/2011	Submitted	
45	Reeling test results - Fi rst amendment	1.0	31	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	13	05/12/2011	Submitted	
1	Requirements specificatio n of the main tether reel	1.0	32	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	11	03/11/2011	Submitted	
2	Design description of the main tether reel	1.0	32	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	11	01/11/2011	Not submitted	
3	Main tether reel test pla n	0.0	32	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	17	01/05/2012	Not submitted	
4	Main tether reel test res	0.0	32	DEUTSCHES	Report	PU	29	01/05/2013	Not submitted	

	ults			ZENTRUM FUER LUFT - UND RAUMFAHRT EV						
1	Requirements specificatio n of the auxiliary tether reel	1.0	33	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	6	09/09/2011	Submitted	
2	Design description of the auxiliary tether reel	1.0	33	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	10	01/12/2011	Submitted	
3	Auxiliary tether reel tes t plan	0.0	33	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	17	01/05/2012	Not submitted	
4	Auxiliary tether reel tes t results	0.0	33	DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV	Report	PU	29	01/05/2013	Not submitted	
1	Requirements specificatio n of the Remote Unit	1.0	41	UPPSALA UNIVERSITET	Report	PU	6	30/06/2011	Submitted	
2	Design description of the Remote Unit	0.0	41	UPPSALA UNIVERSITET	Report	PU	12	01/12/2011	Not submitted	
3	Remote Unit test plan	0.0	41	UPPSALA UNIVERSITET	Report	PU	19	01/07/2012	Not submitted	
4	Remote Unit test results	0.0	41	UPPSALA UNIVERSITET	Report	PU	31	01/07/2013	Not submitted	
1	Final report of Remote Un it power system	0.0	42	TARTU OBSERVATORY -ESTONIAN MINISTRY OF	Report	PU	29	01/05/2013	Not submitted	

				EDUCATION AND RESEARCH						
1	Final report of Remote Un it control and telemetry	0.0	43	UPPSALA UNIVERSITET	Report	PU	29	01/05/2013	Not submitted	
1	Final report of Remote Un it tether jettison	0.0	44	TARTU OBSERVATORY -ESTONIAN MINISTRY OF EDUCATION AND RESEARCH	Report	PU	29	01/05/2013	Not submitted	
1	Final Report of Remote Un it gas thruster	0.0	45	NANOSPACE AB	Report	PU	29	01/05/2013	Not submitted	
1	Simplified FEEP design re port	0.0	46	ALTA SPA	Report	CO	17	01/05/2012	Not submitted	
2	Simplified FEEP test repo rt	0.0	46	ALTA SPA	Report	PU	29	01/05/2013	Not submitted	
3	Cost assessment for indus trial production	0.0	46	ALTA SPA	Report	PU	29	01/05/2013	Not submitted	
1	Simulator user guide	0.0	51	ILMATIETEEN LAITOS	Report	PU	29	01/05/2013	Not submitted	
2	Report of performed runs	0.0	51	ILMATIETEEN LAITOS	Report	PU	35	01/11/2013	Not submitted	
1	Conceptual E-sail designs and specifications for c omponent development	1.0	52	ILMATIETEEN LAITOS	Report	PU	2	17/03/2011	Submitted	
1	Failure mode and recovery strategies analysis repo rt	0.0	53	ILMATIETEEN LAITOS	Report	PU	25	01/01/2013	Not submitted	
2	Refined design concepts d ocument	0.0	53	ILMATIETEEN LAITOS	Report	PU	31	01/07/2013	Not submitted	
1	E-sail mission document	0.0	61	TARTU OBSERVATORY -ESTONIAN MINISTRY OF EDUCATION AND	Report	PU	35	01/11/2013	Not submitted	

				RESEARCH						
1	Summary of orbit calculat ions supporting WP 61	0.0	62	UNIVERSITA DI PISA	Report	PU	35	01/11/2013	Not submitted	
1	Scientific deliverables a s defined in WP 20 – WP 6 0.	0.0	70	ILMATIETEEN LAITOS	Report	PU	35	01/11/2013	Not submitted	
1	Public outreach report	0.0	80	ILMATIETEEN LAITOS	Report	PU	35	01/11/2013	Not submitted	

Milestones

Milestone no.	Milestone name	Work package no	Lead beneficiary	Delivery date from Annex I	Achieved Yes/No	Actual / Forecast achievement date	Comments
1	Remote Unit design parameters fixed	33,41,42,43,44,45,46	5	31/03/2011	Yes	06/04/2011	Most parts already 10/2/2011
2	First tether sample delivered to reeling test	21,31	2	31/03/2011	Yes	16/02/2011	
3	Construction of Remote Unit component prototypes starts	33,41,42,43,44,45,46	5	30/11/2011	No	11/01/2012	Jan 9-10 2012 design approval meeting. Component prototyping work already partly started.
4	100 m tether produced	21	2	30/11/2011	Yes	22/11/2011	67+53 m samples produced already in July 2011
5	Reeling of tether demonstrated	4	4	31/08/2011	Yes	20/07/2011	

4. Explanation of the use of the resources

ILMATIETEEN LAITOS

Work Package	Item description	Amount	Explanations
10	Personnel costs	8175.17	Salaries of Pekka Janhunen, Sini Merikallio and Karita Immonen
24	Personnel costs	29202.76	Salaries of Pekka Janhunen, Petri Toivainen, Sini Merikallio, Jouni Envall and Jouni Polkko
51	Personnel costs	6628.17	Salary of Pekka Janhunen
52	Personnel costs	24655.56	Salaries of Pekka Janhunen, Petri Toivainen, Sini Merikallio, Jouni Envall
70	Personnel costs	21585.41	Salaries of Pekka Janhunen, Petri Toivainen, Sini Merikallio, Jouni Envall
24	Consumables	1557.67	Consumables and related costs
52	Travel costs	289.04	Pekka Janhunen ESAIL project meeting Tartto 8.-11.2.2011
51	Consumables	96.10	Consumables and related costs
70	Travel costs	3790.06	Pekka Janhunen, Sini Merikallio ESAIL project meeting Bremen, Germany 6-8.4.2011; Pekka Janhunen, ESAIL project meeting Uppsala Sweden 29.-31.8.2011; Pekka Janhunen, Sini Merikallio, Jouni Envall ESAIL project meeting Uppsala Sweden 7.-8.11.2011
10	Indirect costs	7398.53	Indirect costs related to the FMI's personnel working hours in WP 10
24	Indirect costs	26428.49	Indirect costs related to the FMI's personnel working hours in WP 24
51	Indirect costs	5998.50	Indirect costs related to the FMI's personnel working hours in WP 51
52	Indirect costs	22313.28	Indirect costs related to the FMI's personnel working hours in WP 52
70	Indirect costs	19534.80	Indirect costs related to the FMI's personnel working hours in WP 70
	Total:	177653.54	

HELSINGIN YLIOPISTO

Work Package	Item description	Amount	Explanations
21	Personnel costs	83085.03	Salary costs of working hours of Henri Seppänen and Jukka Ukkonen; Fees of Sergiy Kiprich
22	Personnel costs	2078.72	Salary costs of working hours of Tuomo Ylitalo
21	Travel costs	8513.35	Sergiy Kiprich, ESAIL project visits, Helsinki, Finland, 23.1.-11.2.2011, 25.4.-11.5.2011, 31.7.-27.8.2011, 6.11.-3.12.2011 (accommodation expenses of the last trip not included); Henri Seppänen, ESAIL project meetings, Tartu, Estonia, 7.-11.2.2011, Bremen, Germany, 5.-8.4.2011, Jyväskylä, Finland, 23.-30.5.2011; Tuomo Ylitalo, ESAIL project meeting, Tartu, Estonia, 9.-11.2.2011; Edward Haeggström, ESAIL project meeting, Uppsala, Sweden, 30.-31.8.2011; Participation fees and mobile internet connection during travel

21	Consumables	4912.22	Materials, equipment and tools for Manual Tether Factory (MTF); Solid Works computer program, webcams and microphones
22	Consumables	100.00	Spray for Tether Coating
21	Indirect costs	57906.36	Indirect costs related to UH input in WP 21
22	Indirect costs	1307.23	Indirect costs related to UH input in WP 22
	Total:	157902.91	

JYVASKYLAN YLIOPISTO

Work Package	Item description	Amount	Explanations
23	Personnel costs	12440.56	Salary costs of Taneli Kalvas and Olli Tarvainen
23	Travel costs	597.01	Taneli Kalvas, meeting, Voore, Estonia 27.-31.10.2011
23	Consumables	149.23	Components for experimental setup in WP 23
23	Indirect costs	7912.08	Indirect costs related to UJ's input in WP 23.
	Total:	21098.88	

DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT EV

Work Package	Item description	Amount	Explanations
31	Personnel costs	15260.23	Salary costs of working hours of Roland Rosta
32	Personnel costs	10188.59	Salary costs of working hours of Tim v. Zoest and Roland Rosta
33	Personnel costs	18552.66	Salary costs of working hours of Tim v. Zoest and Roland Rosta
33	Travel costs	3087.27	Olaf Krömer Esail Kickoff, Helsinki, Finland, 8.-9.12.10; Roland Rosta, ESAIL Design parameter discussoin, Tartu, Estonia, 10.-11.2.2011; Roland Rosta, Olaf Krömer RU Componen Specification Meeting, Uppsala, Sweden, 29.-30.8.2011; Roland Rosta RU Component Design Review Meeting,Uppsala, Sweden, 7.-8.11.2011
31	Consumables	1161.89	Hardware for unreeling tests
32	Consumables	582.28	Hardware parts of the mechanism, Equipment for CAD drawings
33	Consumables	1680.22	Hardware and simple mockup of the mechanism, Service for RU Kickoff Meeting, Bremen 6.-7.4.2011
31	Indirect costs	10529.56	Indirect costs related to DLR's input in WP31
32	Indirect costs	7030.12	Indirect costs related to DLR's input in WP32
33	Indirect costs	12801.34	Indirect costs related to DLR's input in WP33
	Total:	80874.16	

UPPSALA UNIVERSITET

Work Package	Item description	Amount	Explanations

41	Personnel costs	47970.27	Salary costs for Henrik Kratz and Greger Thornell
43	Personnel costs	22224.37	Salary costs for Johan Sundqvist
41	Travel	3520.56	Henrik Kratz ESAIL Kick-off meeting, Helsinki, Finland 8.-9.12.2010; Henri Kratz, Johan Sundqvist and Greger Thornell ESAIL design parameters discussion, Tartu, Estonia 10.-11.2.2011; Henri Kratz, Johan Sundqvist and Greger Thornell ESAIL Remote Unit kick-off meeting, Bremen, Germany 6.-7.4.2011;
41	Consumables	3219.56	Consumables related to work in WP41
41	other costs	605.34	Other services related to the wokr in WP41
41	Indirect costs	33189.42	Indirect costs related to ÅSTC's input in WP 41
43	Indirect costs	13334.63	Indirect costs related to ÅSTC's input in WP 43
	Total:	124064.15	

NANOSPACE AB

Work Package	Item description	Amount	Explanations
45	Personnel costs	172972.65	Salary costs of working hours of Håkan Johansson, Tor-Arne Grönland, Johan Bejhed and Pelle Rangsten
45	Travel costs	3906.49	Håkan Johansson, Tor-Arne Grönland, ESAIL Kick-off meeting, Helsinki, Finland 8.-9.12.2010; Håkan Johansson, Tor-Arne Grönland, ESAIL design parameters discussion, Tartu, Estonia 10.-11.2.2011; Håkan Johansson, Tor-Arne Grönland, ESAIL Remote Unit kick-off meeting, Bremen, Germany 6.-7.4.2011;
45	Consumables	5460.65	Purchasing of test set-up equipment and materials for the gas thruster, for example pressure regulator, mass flow sensor, gas, gas tubing, plastic model of the subsystem.
45	Indirect costs	36467.96	Indirect costs related to Nanospace's input in WP 45
		0.00	
	Total:	218807.75	

TARTU OBSERVATORY -ESTONIAN MINISTRY OF EDUCATION AND RESEARCH

Work Package	Item description	Amount	Explanations
42	Personnel costs	12850.25	Salary costs for Jouni Envall, Kaspars Laizans, Karlis Zalite, Heli Lätt and Silver Lätt
44	Personnel costs	22926.36	Salary costs for Viljo Allik
61	Personnel costs	12779.90	Salary costs for Urmas Kvell, Johan Kütt, Mart Noorma
42	Travel costs	1923.04	Viljo Allik, Jouni Envall: ESAIL project meeting Bremen, Germany 06.-07.04.2011; Viljo Allik ESail project meeting Uppsala, Sweden 29.08-30.08.2011
44	Travel costs	931.95	Mart Noorma meeting in Brussels, Belgium 26.-28.07.2011
61	Travel costs	378.20	Viljo Allik ESAIL project meeting Uppsala,

			Sweden 7.-8.11.2011
42	Consumables	6666.18	Electronical components, materials and consumables for RU design and experimenting
44	Consumables	919.65	Electronical components, materials and consumables for jettison system design and testing
42	Indirect costs	4287.89	Indirect costs related to Tartu's input in WP 42
44	Indirect costs	4955.59	Indirect costs related to Tartu's input in WP 44
61	Indirect costs	2631.62	Indirect costs related to Tartu's input in WP 44
		0.00	
	Total:	71250.63	

UNIVERSITA DI PISA

Work Package	Item description	Amount	Explanations
62	Travel costs	1121.66	Alessandro Quarta and Generoso Aliasi, Kickoff meeting, Helsinki Finland, 8-9.12.2010
62	Indirect costs	673.00	Indirect costs related to Pisa's input in WP62
	Total:	1794.66	

ALTA SPA

Work Package	Item description	Amount	Explanations
46	Personnel costs	28919.00	Salary costs of Pierpaolo Pergola Project Manager; Giovanni Cesaretti, Nicola Giusti and Salvo Marcuccio Senior Engineer; Andrea Ruggiero Junior Engineer; Massimo d'Urso technician
46	Travel costs	5344.00	Nicola Giusti, Pierpaolo Pergola, Remote Unit Kick-off (2 persons), 09-11.2.2011 Tartu Estonia; Nicola Giusti, Pierpaolo Pergola, Remote Unit Component Specification (2 persons) 05-07.4.2011 Bremen Germany; Nicola Giusti, Pierpaolo Pergola, Salvo Maruccio, Remote Unit Component Design Review (3 persons) 29-31.8.2011 Uppsala Sweden;
46	Consumables	2467.00	Materials and components for test setup and for test setup management and control
46	Indirect costs	22038.00	Indirect costs related to ALTA's input in WP46
	Total:	58768.00	

Attachments	advertisement-slides.pdf, report.pdf
Grant Agreement number:	262733
Project acronym:	ESAIL
Project title:	Electric sail propulsion technology
Funding Scheme:	FP7-CP
Project starting date:	01/12/2010
Project end date:	
Name of the scientific representative of the project's coordinator and organisation:	Dr. Pekka Janhunen ILMATIETEEN LAITOS
Period covered - start date:	01/12/2010
Period covered - end date:	30/11/2011
Name	
Date	

This declaration was visaed electronically by Pekka JANHUNEN (ECAS user name njanhupe) on

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PROJECT PERIODIC REPORT (Core)

Grant Agreement number: 262733

Project acronym: ESAIL

Project title: Electric Sail Propulsion Technology

Funding Scheme: Collaborative Project

Date of latest version of Annex I against which the assessment will be made:

Periodic report: 1st X 2nd ☐ 3rd ☐ 4th ☐

Period covered: from Dec 1, 2010 to Nov 30, 2011

Name, title and organisation of the scientific representative of the project's coordinator[1]:

Pekka Janhunen, Research Manager, Finnish Meteorological Institute, Helsinki, Finland

Tel: +358-9-19294635

Fax: +358-9-19294603

E-mail: pekka.janhunen@fmi.fi

Project website[2] address: http://www.electric-sailing.fi/fp7

[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement .

[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

3.2 Core of the report for the period: Project objectives, work progress and achievements, project management

3.2.1 Project objectives for the period

The Electric Solar Wind Sail (E-sail) is a recent invention of ultra-efficient propellantless in-space propulsion technology. It uses the solar wind charged ions as natural source for producing spacecraft thrust. The E-sail is composed of a set of long, thin, conducting and positively charged tethers which are centrifugally stretched from the main spacecraft and kept electrically charged by an onboard electron gun powered by solar panels.

The E-sail concept is an enabling technology for reducing significantly the time, cost and mass required for spacecraft to reach their destinations. It has been estimated that it has the potential to improve the state of the art of propulsion systems by 2 to 3 orders of magnitude if using the lifetime-integrated total impulse versus propulsion system mass as the figure of merit. Furthermore, the E-sail propulsion technology is truly a green propellantless method reducing significantly the mission launch masses and the amount of chemical propellant burnt in the atmosphere. As an electromechanical device it does not need any poisonous, explosive or radioactive substances or dangerous construction procedures.

In the ESAIL project we develop the key E-sail technologies (tethers, tether reels, spinup and guidance/control method based on gas and FEEP thrusters) to prototype level. The goal is that after the project, the decision to build and fly the first E-sail demonstration mission in the solar wind can be made. As a secondary technological goal, the project will raise the FEEP and gas thruster readiness level for general-purpose satellite attitude control purposes.

Five milestones were to be reached during the first year:

MS1: Remote Unit design parameters fixed
MS2: First tether sample delivered to reeling test
MS3: Construction of Remote Unit component prototypes start
MS4: 100 m tether produced
MS5: Reeling of tether demonstrated

All milestones except MS3 were reached, some (MS4, MS5 and partly MS1) were reached ahead of time. MS3 will be reached soon: in January 9-10 we'll have a project meeting where the Remote Unit CAD design should be approved and the Remote Unit testing procedures will be planned. In some sense MS3 has already been reached, though, since some Remote Unit component prototyping work has already been ongoing for months (e.g., the FEEP thruster).

3.2.2 Work progress and achievements during the period

WP21 Tether factory

The tether factory work has proceeded as planned, “Stage 1” (100 m capable factory) is completed and some “Stage 2” work (looking at material wear) has already been done. A lot of work on developing online quality control methods based on contact resistance measurement and propagation of laser-generated ultrasonic pulse through the bond has been done. The first 120 m long tether was produced already in summer 2011, well ahead of time, although it broke at the middle by a mishap. In November 2011 a continuous 100 m tether was successfully produced.

WP22 Tether coating

Various aluminium wire tether coating options have been tested in practice, including a commercial hexagonal boron nitride spray, tungsten disulphide spray, water vapour induced aluminium oxide and aluminium oxide by atomic layer deposition (ALD). The sprays attached on the wire surface, although the materials' particle size is of the same order as the wire diameter so the “coating” is far from ideal. The aluminium oxide processes also worked. ALD seems to be the most promising because it produces a uniform oxide layer. The next step is to test if ALD can be used to coat the entire reel-stored tether after manufacture by one run of the ALD reactor. That would be an ideal solution.
A setup for measuring the infrared emittance of a wire has been created in Jyväskylä and tested for an uncoated wire thus far.

WP23 Tether testing

Tether testing has been somewhat reoriented from the DoW. The original WP description mainly speaks about the effect of charged particle fluxes (especially the solar wind electron flux accelerated by the tether's voltage) on the tether and its coating. However, we deem it necessary to measure the infrared emittance of the coated tether (or wire), because table values might not be trustable in this case and because an important goal of the coating is to reduce the tether's equilibrium temperature in space with respect to bare aluminium. A setup for measuring the infrared emittance was therefore built in Jyväskylä. The setup contains an evacuated chamber with the tested wire inside. The wire is heated resistively by passing a significant current through it while monitoring the potential drop to measure the resistivity. The temperature of the wire is then inferred from the known dependence of the aluminium resistivity on temperature. The reference measurements with uncoated wire has been done.
Charged particle tests have not yet been done because we think that they have lower priority than the infrared emittance measurement: if the selected coating is inorganic (e.g., aluminium oxide), it is almost clear even without measuring that electron flux will not cause any problems. Nevertheless, preparations for building the electron bombardment setup are underway.

WP24 Auxiliary tether

We decided to concentrate only on the stretched auxtether variant (Task 2) and skip the more elementary Task 1 because it turned out that the stretched variant provides key mass saving and robustness benefits for the E-sail as a whole.
The baseline auxtether is a 3 cm wide kapton tape that is patterned with suitable holes to produce the wanted elastic constant. The goal of the WP is to acquire or produce short tether samples and to characterise their suitability.
We have now samples of 3 cm wide and 12.6 um thin polyimide tape (stored on reels) and about 50 cm long patterned samples made of it by two different techniques (photoetching and laser cutting). Both patterning methods produced a very good result. Preliminarily it looks that by patterning the tether, the wanted elastic coefficient can be produced, and the patterned tether also tends to naturally bend into a 3-D shape which is very resistant towards micrometeoroids. The main remaining task in patterning would be to develop a roll-to-roll method suitable for mass production (not attempted). The laser cutting method seems better suited for mass production. We are now close to having done the tasks that were planned for WP24.
This WP was delayed, mainly because it took much longer time than what we anticipated to acquire thin polyimide tape from suppliers and then to get other companies to pattern them. We searched a much larger number of companies than who finally delivered. Fortunately, this delay did not induce other delays, because the critical parameters of the auxtether (width and thickness) that are needed in other WPs were frozen in an early enough phase.
We have now used approximately the originally planned resources and we essentially have the results at hand. However, we would like to extend the WP's scope a bit by investigating Dyneema auxtether solutions. If successful, tethers weaved in some way of Dyneema might use clearly less reel space on the Remote Unit for the same length. We have already verified that commercial Dyneema fishing line carries large loads also at cryogenic temperature. We would like to continue by verifying UV and particle radiation tolerance and by investigating knotting methods for weaving a tether. This needs some more person months which we would like to take from another FMI WP, namely WP51 (Dynamical simulation).

WP31 Reeling tests

For the experimental testing of tether reeling, four reels were designed and built with varying diameter and edge shapes. With each of the four reels, tether tests were carried out to investigate in the behaviour of the tether during unreeling.
All reeling tests were completely successful at the tested 10 m tether length. This is important for the general feasibility of the E-sail. The WP used the planned amount of resources.

WP32 Main tether reel

Based on the reeling test (WP31) the main tether reel deployment mechanism is designed. The design contains the tether reel, the motor, the slip ring, the isolation as well as the tether cutter. The first design of the main tether deployment was accomplished. This WP is somewhat shadowed by a fact which was realised during the project that before knowing how many layers of tether can be reliably reeled on top of each other (and that can be studied experimentally only after we have manufactured hundreds of metres of tether, preferably 1 km, which is the tether production's end goal), it is difficult to know the optimum final shape and diameter of the main tether reel for a given tether length.

In other words, there is a hidden dependency between WPs that was not realised in the planning stage. For this reason, WP32 is not among our top priorities right now, although we are proceeding with it. Technically the work appears to be straightforward once the geometric design parameters are clear.

WP33 Auxiliary tether reel

For the design of the auxiliary tether deployment mechanism, a few designs were created and evaluated. For the final design, the best rated concept was chosen. It consists of the motor which controls the unreeling, the motor holder as an interface between the remote unit and the deployment mechanism as well as the tether reel. This WP is now almost in schedule and according to specifications and almost on time (about 1 month late as the rest of the Remote Unit). During the work we had a mass issue at one point and some interfacing issues with the rest of the Remote Unit. The issues are now resolved.

WP41 Remote Unit overall design

The overall design of the Remote Unit very central for the E-sail and consequently the Coordinator has paid a lot of attention to it. The Remote Unit is a small autonomous unit carrying the auxtether reels and gas or FEEP thrusters for creating the initial E-sail angular momentum and perhaps for later controlling the spinrate if needed. The unit receives radio commands from the main spacecraft (maximum 20 km away) and can send back diagnostic data. The needed data rates and processing power are low. The solar-powered Remote Unit must remain operable in the rather wide solar distance range of 0.9-4 AU, although the reels and their motors only have to work for a few weeks during deployment. It has no ACS because the stretched tethers keep it in the correct attitude. In order to get a full-scale 1 N E-sail's mass below 100 kg, the Remote Unit should be lighter than 0.5 kg.
We think that we have a very good overall Remote Unit design now which satisfies all the requirements while being compact, simple, robust and also amenable to serial production (needed in the future for full-scale E-sails). To a certain extent, the design is also modular in the sense that it allows modifying the auxtether reel volumes, for example, without completely redesigning the unit. The concept is based on a thermally insulated box located behind a sun shield that also contains the solar panels, thus exploiting the fact that the same face of the unit is always facing the sun. The thermal box contains the power system, control electronics and the thruster. The reels and their motors (placed inside reel axes) are placed openly at the perimeter of the unit. They need not be thermally controlled, because they are needed only during deployment close to 1 AU. During launch and before deployment in space, the Remote Unit is attached to the main spacecraft from the the auxtether reels (the attachment doubles as a launch lock for the reels) and from the thermal box. This arrangement is made so as to be able to keep the mechanical interface between the thermal box and the sun shield thin, which reduces thermal leaks from the box to the sun shield enough that the thermal box can retain sufficient internal temperature even up to 4 AU while using only 17x17 cm solar panel area. At 4 AU, all power is dissipated within the thermal box to keep it warm, while at 0.9 AU most of the power produced by the solar panels is dumped to a hot space-facing radiator. The reel motors are placed inside the reel axes outside the thermal box, so that during deployment at 1 AU, thermal power dissipated by the motors does not cause the thermal box to overheat.

The work is almost on schedule (1 month late) and has used slightly more resources than originally estimated.

WP42 Remote Unit power system

The Remote Unit power system design has proceeded smoothly. No problems surfaced and the requirements were satisfied properly.

WP43 Remote Unit control and telemetry

The Remote Unit control and telemetry design has also proceeded smoothly. A simple and low mass, low power solution was identified and designed without problems.

WP44 Remote Unit tether jettison

Designing the Remote Unit tether jettison mechanism has also gone without problems. Several technical solutions were evaluated and a simple and reliable one was selected. The jettisoning system is needed only if one of the main tether breaks so in nominal operation this subsystem is not invoked.

WP45 Remote Unit gas thruster

The gas thruster will use butane propellant stored as a liquid in the tank and let to evaporate when used. The propellant selection was made during the project, based on evaluating many propellants for our required properties such as specific impulse, density, temperature requirements and the artificial milligravity environment on the Remote Unit.
The present gas thruster design is quite efficient in terms of volume usage. It is also modular because the geometry is such that it can be fit in a CubeSat directly. Indeed, the plan is to test it in the QB-50 mission later. No problems have thus far arisen in this WP and the resource usage has been nominal.

WP46 Remote Unit FEEP thruster

For low cost, low mass, robustness and simplicity, the FEEP thruster developed for the E-sail Remote Unit will employ ionic liquid propellants (organic molten salt) and not alkali metals (e.g. caesium). Ionic liquids can be handled in air with no special precautions and are compatible with a large variety of materials. The FEEP thruster development has gone well, a thruster prototype was successfully fired with EMI-BF4 propellant in vacuum chamber and its beam was scanned by two probes (in the vertical and horizontal planes) and time of flight techniques (to detect beam species). No problems have arisen in this WP and the resource usage has been nominal.

WP51 Dynamical simulation

Work with the dynamical simulation was commenced right when the project started, to support the decision making of the selection of the E-sail tether geometry. After that, work has continued at a lower level. The dynamical simulator exists and can be used. We will add features to it when needs arise. This WP will likely require less resources than originally planned. Those resources would be moved to WP24 (auxiliary tether).

WP52 Design concepts

This was a hectic 3-month period at the start of the project which was fundamental to the rest of the activity. We evaluated different E-sail geometries and selected the best one based on dynamical simulations (WP51) and other considerations. We found a solution which is better than the one foreseen in the plan. The employed solution is based on stretched auxiliary tethers. By implementing the chosen solution, the ESAIL project will yield a better outcome than originally thought possible.

WP70 Scientific coordination

This is the coordinator's activity to lead the project scientifically. It is needed because the coordinator is also the inventor of the E-sail technology.

Overview

Overall, the project has gone very well. In many regards we are on a way of exceeding the original specifications (e.g., better overall E-sail solution, probably will reach higher TRL, tether manufacture is ahead of schedule etc.). In some other respects we are slightly lagging in schedule (e.g., Remote Unit design by about 1 month). In the auxiliary tether WP (WP24) we are lagging significantly due to delays in acquiring materials etc., but in a way which does not harm other WPs. The main technical challenges encountered during the reporting period were related to the auxiliary tether reels and finding a good, low-mass solution for the Remote Unit as a whole.

3.2.3 Project management during the period

The consortium management was in general unproblematic, there were no disputes to be resolved and the management could therefore concentrate on routine tasks: meetings, gathering and editing deliverables and other data plus financial management. We think that management works well when it's invisible and we think that this goal was reached well during the first year of the ESAIL project.
During the first year there were no changes in the Consortium and no deviations from the DoW, except that in many deliverables we were late by 1-2 months. The auxiliary tether deliverable (WP24) was not submitted before the end of the period, although it was scheduled for Month 6; a warning was sent to the Project Officer about this significant delay.
The following project meetings were held during the period (Dec 1 2010- Nov 30 2011):

Meeting	Date	Location	Participants
ESAIL kickoff	8-9 Dec 2010	Helsinki	All
Design parameters discussion	10 Feb 2011	Tartu	All but UJ and Pisa
Remote Unit kickoff	6-7 Apr 2011	Bremen	RU team
Reeling test 1st review	6-7 Apr 2011	Bremen	DLR,UH,FMI
Tether testing kickoff	26 May 2011	Jyväskylä	UJ,UH
Remote Unit component specs	29-30 Aug 2011	Uppsala	RU team
Remote Unit component design review I	7-8 Nov 2011	Uppsala	RU team

The meetings were arranged as planned in the DoW but with the following exceptions:

- Remote Unit kickoff meeting and Reeling test 1st review meeting were arranged in temporal succession in Bremen, to rationalise logistics and minimise travelling
- An extra Remote Unit component design meeting was arranged in Jan 2012 (after the period in question here), hence the first one is named meeting number "I". The reason for arranging an extra meeting was that the Remote Unit mass was too high at the first meeting and significant mass reduction possibilities were foreseen so that the mass goal of 0.5 kg stated in the DoW could be achieved, or nearly achieved.
- Reeling test 2nd and 3rd review meetings were not held. Reeling tests succeeded without problems and thus there was no need for these meetings. (However, as a deviation from the DoW, we are proposing to resume reeling tests with 100 m and 1 km tether later in the project.)

The ESAIL project public website was set up and the address is http://www.electric-sailing.fi/fp7. In addition, private ESAIL Team Pages were set up which contain more information for internal use, at address https://www.electric-sailing.fi/fp7s. The Team Pages are password protected and the password has been communicated to the Evaluator and the Project Officer separately. In particular, the Team Pages contain the agendas, the minutes, the presentations and some photographs from each project meeting. The Team Pages also contain copies of the delivered deliverables, a template for new deliverables, list of the WP descriptions, the full DoW and different versions of the ESAIL project logos for partners to use.

Related electric sail activities outside the ESAIL project

At least the following related E-sail activities were ongoing during the period:

- ESTCube-1 nanosatellite project (Tartu, FMI, UH, UJ, DLR)
- Aalto-1 nanosatellite project (Aalto University, FMI, UH, UJ, DLR)
- SWEST new FP7 proposal (FMI, Alta, UH, UJ, Nanospace, Alta, Tartu, Fachhochschule Wiener Neustadt)
- Internal working group at ESA/ESTEC organised by Jose Gonzalez del Amo, whose target is to make recommendations concerning possible future scientific ESA missions using electric sail and photon sail technologies (member of the group: Urmas Kvell, Tartu)
- Academy of Finland project "Scientific applications of the electric sail"
- Discussions with Swedish National Space Board concerning possible flight demonstrations of sub-technologies needed by the E-sail using nanosatellites, minisatellites or sounding rockets