SREEPATHY INSTITUTE OF MANAGEMENT AND TECHNOLOGY
VAVANOOR, KOOTTANAD, PALAKKAD (Dt), KERALA
PIN:679121, Ph:91+0466-2370200

DEVELOPMENT OF SOLAR FILM-BASED POWER SOURCE FOR FLAPPING WING UNMANNED MINI/MICRO AIR VEHICLE

CLOSURE REPORT

Reference to AR&DB I sanction : ARDB/01/2021782/M/I dt.25.8.15

V M DILEEPAN, Dept of Electrical and Electronics Engineering
KT MADHAVAN, R & D Unit

March, 2017

GRANTS-IN-AID SCHEME:
AERONAUTICS R&D BOARD
PROFORMA FOR CLOSURE REPORT OF WORK DONE ON SANCTIONED PROJECTS

NB-1: **Two copies** (one ink signed) of the report are required

NB-2: The Closure report will cover work done during the period of the project.

PART I

Name of the Research Panel: Special Interest Group on Micro Air Vehicles (SIGMA)

1. Name & Designation of Investigators : V M Dileepan, Asst. Prof., EEE Dept
K T Madhavan, Professor, R & D

2. Name & Address of Institution : Sreepathy Institute of Management and Technology, Vavanoor, (Via) Koottanad, Plalakkad Dt., Kerala, PIN-679533

3. Title of Project : **Development of Solar Film-based Power Source for Flapping Wing Unmanned Mini/Micro Air Vehicle**

4. Sanction Letter No. Reference : ARDB/01/2021782/M/I dt.25.8.15

5. Period for which sanctioned : 12 months

6. Date of commencement of work : 17.12.2015
(The project would be deemed to be operative with effect from the date funds are received by the Institution)

7. Total Amount Sanctioned : Rs.4.75 Lakhs

YEAR	RESEARCH STAFF (mention no. with qualification)	EQUIPMENT				TRAVEL	CONTIN-GENCIES	OTHERS (Overheads)
		CAPITAL		CONSUMABLE		(TA/DA)		
		IC	FE	IC	FE			
1st	NIL	1.2		3.15		0.05	0.10	0.25

8. Statement of accounts certified by competent authority (Likely unspent balance at the time of expiry of the period and the saving made, if any, under different heads should be clearly indicated)

STATEMENT OF ACCOUNTS

9.

Period	HEADS	Grant Released (under different heads)	Expenditure incurred (under different heads)	Balance (under different heads)
1	2	3	4	5
	Staff	NIL	NIL	NIL
	Capital Equipment	1.20	1.20	0.00
	Consumables	3.15	3.15	0.00
	TA/DA	0.05	0.05	0.00
	Contingencies	0.10	0.10	0.00
	Others: (Specify as per Initial sanction letter) Overheads	0.25	0.25	0.00
	Interest Accrued	0.00	0.00	0.00
Total (Rs.Lakhs)		**4.75**	**4.75**	**0.00**

9. Details of staff in position (indicating change, if any) : NIL

Year	Designation of Post (s) with pay as sanctioned	Name(s)	Qualifications & Experience	Date of appointment	Date of resignation	Period for which employed
1	2	3	4	5	6	7
-----	-----	-----	-----	-----	-----	-----

GRANTS-IN-AID SCHEME:
AERONAUTICS R&D BOARD
PROFORMA FOR ANNUAL PROGRESS AND CLOSURE REPORTS

Institute Reference		
Information on Grants-in-Aid project of Aeronautics Research & Development Board sanctioned to :		Sreepathy Institute of Management and Technology, Vavanoor, (Via) Koottanad, Plalakkad Dt., Kerala, PIN-679533
1.	Reference to AR&DB initial sanction :	ARDB/01/2021782/M/I dt.25.8.15
2.	Project Title :	Development of Solar Film-based Power Source for Flapping Wing Unmanned Mini/Micro Air Vehicle
3.	Name of Principal Investigator :	V M Dileepan, Asst. Prof., EEE Dept K T Madhavan, Professor, R & D Unit
4.	Duration of the project, together with revisions in PDC, if any :	12 months
5.	Total Funds for the duration of the project including FE	Rs.4.75 Lakhs

Total amount sanctioned	**Heads under which grant released**				**Year wise Date of sanction of funds**			**Date of receipt of funds**		
(Rs. in lakhs)		Ist	II	III	Ist	IInd	IIIrd	Ist	IInd	IIIrd
4.75	Capital Equipment	1.20	--	--	17.12.16	--	--	17.12.16	--	--
	Consumables	3.15	--	--	17.12.16	--	--	17.12.16	--	--
	TA/DA	0.05	--	--	17.12.16	--	--	17.12.16	--	--
	Contingencies	0.10	--	--	17.12.16	--	--	17.12.16	--	--
	Others: (Specify as per Initial sanction letter) Overheads	0.25	--	--	17.12.16	--	--	17.12.16	--	--
	Interest Accrued	0.00	--	--	17.12.16	--	--	17.12.16	--	--

Signature of the Executive Authority/ Head of the Institution	Signatures of the PIs	Signature of the Accounts Officer	Signature of the Audit Authority
Principal Sreepathy Institute of Management and Technology, Vavanoor-679 533	1. (DILEEPAN.V.M) 2. (K.T.MADHAVAN)	SASIKUMAR.K	C. S. NARAYANAN NAMBOODIRI CHARTERED ACCOUNTANT Membership No. 201525 BRAHMASWAM MADAM BUILDING M. G. ROAD TRISSUR-680 001.
Date : 17/2/2017	Date : 17/02/2017	Date : 17/02/2017	Date : 17/02/2017

STATEMENT OF EXPENDITURE

Year	Salary/ Wages Allowances	Consumable Material	Capital Equipment		TA/ DA	Contin- gencies	Any other heads	Total Expen diture	Balance
			Indian	Foreign					
a	b	c	d	e	f	g	h	i	j
2015-2016	-----	3.15 Lakhs	1.20 L	N A	0.05 L	0.10L	0.25L	4.75L	0.00
Total:	-----	**3.15 Lakhs**	**1.20 L**	**N A**	**0.05 L**	**0.10L**	**0.25L**	**4.75L**	**0.00**

Signature of the Executive Authority/ Head of the Institution	Signatures of the PIs	Signature of the Accounts Officer	Signature of the Audit Authority
Principal Sreepathy Institute of Management and Technology, Vavanoor-679 533	1. DILEEPAN.V.M. 2. LKTMADHAVAN	Sasikumar CK	C. S. NARAYANAN NAMBOODIRI CHARTERED ACCOUNTANT Membership No. 201525 BRAHMASWAM MADAM BUILDING M. G. ROAD THRISSUR-680 001.
Date : 17/2/2017.	Date : 17/02/2017	Date : 17.02.2017	Date : 17/2/2017

UTILISATION CERTIFICATE

(Period December, 2015 to December, 2016)

1. Certified that out of a sum of Rs.4.75 Lakhs of Grants-in-Aid sanctioned during the year 2016-201in favour of Sreepathy Institute of Management and Technology, Vavanoor, (Via) Koottanad, Plalakkad Dt., Kerala, for carrying out R.& D work on **Development of Solar Film-based Power Source for Flapping Wing Unmanned Mini/Micro Air Vehicle** under Govt of India, Grant-in-Aid Scheme, Ministry of Defence , Directorate of Aeronautics , Aeronautics Research & Development Board sanction letter mentioned below :

   No. and date of the sanction letter : ARDB/01/2021782/M/I dt.25.8.15

   A sum of **Rs. NIL** interest accrued on the above amount. In case, interest not accrued justification for the same may be given.

   A sum of Rs.4.75 Lakhs has been utilised for the purpose for which it was sanctioned and that the balance of Rs.Nil remaining unutilized at the end of the year / completion of the scheme and the interest accrued amount of Rs 0.00 (Total Amount Rs.0.00) has been refunded to the Govt. Vide (prescribed format) MRO No. *NA* (Original copy enclosed).

2. It is further certified that I have satisfied myself that the conditions on which Grant-in-Aid was sanctioned have been duly fulfilled and that I have exercised necessary check to see that the money was actually utilised for the purpose for which it was sanctioned.

(Signature) (Signature)

Principal Investigators
1. DILEEPAN.V.M.
2. K T MADHAVAN

Place: Vavanoor

Date : 17/02/2017

Principal
Sreepathy Institute of Management and Technology, Vavanoor-679 533

(Signature)
Executive Authority of the Institution

Place:

Date :

SREEPATHY INSTITUTE OF MANAGEMENT & TECHNOLOGY * VAVANOOR *

COUNTERSIGNED CORRECT

(Signature)
AUDIT AUTHORITY OF THE INSTITUTION

C. S. NARAYANAN NAMBOODIRI
CHARTERED ACCOUNTANT
Membership No 201525
BRAHMASWAMMADAM BUILDING
M. G. ROAD
THRISSUR-680 001.

Place: Thrissur

Date : 17/02/2017

REFUND OF UNSPENT BALANCE & ACCRUED INTERSET
(NOT APPLICABLE)

A sum of Rs. ____________ interest accrued on the above amount. (In case, interest not accrued justification for the same may be given.)

Justification:

The balance of Rs.____________________ remaining unutilized at the end of the year / completion of the scheme has been refunded to the Govt. Vide (prescribed format) MRO No. ________ and date ______ (Original copy enclosed). OR Demand Draft No ……………. Dated ……..for the balance amount Rs ……………. in favour of **"PCDA New Delhi"** is enclosed.

NOTE:

AR&DB has not permitted the utilization of accrued Interest by the PI. The institute is to therefore Refund the Interest accrued plus the unspent balance to AR&DB.

Form GFR 19

All equipments purchased should be serially numbered. An inventory of the equipment purchased out of the grant should be sent to the Secretary, Aeronautics R&D Board in form GFR 19 along with the periodical reports in 3 ink signed copies. The inventory should give the description of the equipment (whether expendable or non-expendable), its cost in rupees, date and purchase and the name of the supplier.. The auditors should be requested to issue a certificate that necessary check has been made and the inventory is found to be in order. The inventory and the requisite certificate from the auditor should be furnished along with the audited accounts. The equipment / surplus stores will be the property of the Aeronautics R&D Board who will be responsible for its future transfer / disposal after the termination of the project.

The Board at the written request of the grantee institution may agree to out-right transfer of some or all equipment of the AR&DB inventory to the institution concerned based on the recommendations of the concerned panel. The Grantee institution is to make the request listing all the equipment acquired through this project in the Form GFR 19 appended below.

To
Secretary, AR&DB
1. Appended below please find list of all the equipment acquired through this project as per GFR 19.

EQUIPMENT HEAD /CAPITAL					
SL NO	ITEM	DESCRIPTION	QTY	AMOUNT/UNIT	TOTAL AMOUNT
1	SOLAR CHARGE CONTROLLERS	TO GET A STABLE OUPUT	4	941	3764.00
2	SOLDERING IRONs	SOLDERING Equipment	4	650.00	2600.00
3	BATTERY CLAMPS	CONNECTION	10	500.00	6000.00
4	ORNITHOPTER MODEL	POER SOURE TESTS	2	2887.00	5774.00
5	ORNITHOPTER FLAPPER/WING	TO PASTE THE SOLAR CELLS& TESTING OF POWER EXTRACTION (1200mm*210mm)	1	17500.00	17500.00
6	BLDC MOTOR	WING POWER	4	456.00	1824.00
7	ESC CONTROLLER	PULSE OUTPUT	5	470.00	2350.00
8	TRANSCIEVER	COMMUNICATION & CONTROL OF FLIGHT	2	2727.00	5454.00
9	BATTERY CHARGER	TO CHARGE THE BATTERY	2	1340.50	2681.00
10	Li-Po BATTERIES	POWER SUPPLY/11.1V/ 1000MAh(25C)/2200mAh(30C)/3CELL	2	2309.00	4618.00
11	RELAY MODULE	COMMUNICATION & CONTROL OF FLIGHT	10	195.00	1950.00
12	ARDUINO & RASPBERRY PI	CONTROL SYSTEM PROGRAM	1	3334.00	3334.00
13	CONTROL CIRCUIT DESIGN SOFTWARE & MODELING & ASSEMBLING/CD	CONTROL BOARD DEVELOPED	1	60000.00	60000.00
14	ELECTRONIC MODULES FOR CONTROLLER	FOR CHARGE CONTROL SYSTEM		2151.00	2151.00
NET AMOUNT		(ONE LAKH TWENTY THOUSAND ONLY)			120000.00

17/02/2017

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THRISSUR-680 001.

DILEEPAN.V.M.
K T MADHAVAN

Signatures of PIs

SREEPATHY INSTITUTE OF MANAGEMENT & TECHNOLOGY

Principal
Sreepathy Institute of Management and Technology, Vavanoor-679 533

(Executive Authority of the Institute)

SASIKUMAR CK

Signature of Accts Offr

Secretary
SREEPATHY TRUST
[illegible] SWAMIYAR MADHOM
THRISSUR- 680 001

Application for Retention of Special Equipment as per GFR -19

To

Secretary, AR & DB

1. Appended below please find list of all the equipment acquired through this project as per GFR 19.

Sl No	Name of gran-tee Institution	No & Date of sanction	Amount of grant San-ctioned Total	Brief purpose of the grant	If any condition regarding the right of ownership of Govt. in the property or other assets acquired out of the grant was incorporated in the grants in aid sanction	Particulars of assets credited or acquired	Value of the assets as on 12.08.16	Purpose of which utilized at present	Encumbered or not	Reason if encumbered	Disposed or not	Reason and authority of disposal	Amount realized on disposal	Remarks
1	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala, PIN-679582 Plalakkad Dt., Kerala	ARDB/01/20217 82/M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Flapper Ornithopter model	Rs. 17,500	For evaluation of solar power source in static and flapping cases	Encum-bered	N A	No	NA	NA	—

17/02/2017

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1. DILEEPAN V.M

2. (K T MADHAVAN)

Signatures of PIs

SREEPATHY INSTITUTE OF MANAGEMENT & TECHNOLOGY

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Sreepathy Institute of Management and Technology, Vavanoor-679 533

(Executive Authority of the Institute)

SASIKUMAR C K

Signature of Accts Offr

Secretary
SREEPATHY TRUST
KE SWAMIYAR MADHOM
THRISSUR- 680 001

2	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala , PIN-679582 Plalakkad Dt.,	ARDB/01/2021782/M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	BLDC MOTORs	Rs.2280	For flapping the wing	Encum-bered	N A	No	NA	NA	-----
3	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala , PIN-679582 Plalakkad Dt.,	ARDB/01/2021782/M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Solar charge controller	Rs. 3770	To achieve stable solar output	Encum-bered	N A	No	NA	NA	-----
4	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala ,	ARDB/01/2021782/M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Trans-ciever	Rs.2727	For data transmission to and from flapper	Encum-bered	N A	No	NA	NA	-----

17/02/2017

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2. (K T MADHAVAN)

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SASIKUMAR C K

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NEDUMKE SWAMIYAR MADHOM
THRISSUR- 680 001

5	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala, PIN-679582	ARDB/01/20217 82/M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Battery clamps	Rs1697	For Li-Po Battery Connections To	Encum-bered	N A	No	NA	NA	----
6	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala, PIN-679582 Plalakkad Dt.,	ARDB/01/20217 82/M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Omitho-pter Wing Model	Rs.2887	For data transmission to and from flapper	Encum-bered	N A	No	NA	NA	----
7	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala, PIN-679582	ARDB/01/20217 82/M/I Sanctin date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Electronic Speed Controller (ESC) for BLDC	Rs.1880	For data trans-mission and control of BLDC motor	Encum-bered	N A	No	NA	NA	----
8	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala, PIN-679582	ARDB/01/20217 82/M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Arduino & Rasp-berry Micro Controller Board	Rs.2727	For data transmission to and from flapper	Encum-bered	N A	No	NA	NA	----

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9	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala , PIN-679582	ARDB/01/ 2021782/ M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Control Circuit Design Software, Modeling & Assembly	Rs.60000	For data trans-mission and control	Encum -bered	N A	No	NA	NA	-----
10	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala , PIN-679582	ARDB/01/ 2021782/ M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Power Supply Modules (Li-Po Battery sets)	Rs.4618	For circuit boards data acquisition and control	Encum -bered	N A	No	NA	NA	-----
11	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt.	ARDB/01/ 2021782/ M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flap-ping wing	Nil	Battery charging unit	Rs.2681	For data transmission to and from flapper	Encum bered	N A	No	NA	NA	-----

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12	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala , PIN-679582	ARDB/01/ 2021782/ M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Soldering equipment	Rs.2600	For data transmission to and from flapper	Encumbered	N A	No	NA	NA	-----
13	Sreepathy Institute of Management & Technology nology, Vavanoor, Koottanad, Palakkad dt., Kerala , PIN-679582	ARDB/01/ 2021782/ M/I Sanction date 17.12.16	Rs. 1.20L	Development of solar-based power source for flapping wing MAV	Nil	Relay Module	Rs.1950	Communication & Control Of flapper	Encumbered	N A	No	NA	NA	-----

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SASIKUMAR C.K.
Signature of Accts Offr

Secretary
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[illegible] SWAMIYAR MADHOM
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EXECUTIVE SUMMARY OF PROJECT

1 Title of the Project	Development of Solar Film-based Power Source for Flapping Wing Unmanned Mini/Micro Air Vehicle	
2. Cost of the Project	Date of Sanction	Date of Completion
Rs.4.75 Lakhs 1. T	17.12.2015	2.12.2016

1. Title of the Project : **Development of Solar Film-based Power Source for Flapping Wing Unmanned Mini/Micro Air Vehicle**

2. Name of the Principal Investigator: **V M Dileepan, Asst. Prof., EEE Dept**
Dr.K T Madhavan, Professor, R & D

3. Name of the Institution : Sreepathy Institute of Management and Technology, Vavanoor, (Via) Koottanad, Plalakkad Dt., Kerala, PIN-679533

4. Cost of the project : Rs.4.75 Lakhs

5. Date of Sanction : 17.12.2015

6. Date of completion : 27.12.2016

7. Aim of the project:

(i) Development of power generation scheme based on thin film solar cells and storage of solar power by means of inverter and battery

(ii) Implementation of the scheme on typical fixed/ flapping wings used in unmanned aircraft

(iii) Laboratory level demonstration of the scheme

8. Requirement Envisaged : Please see Appendix I

9. Achievements: Please see Appendix I,II

10. Likely Applications of the Outcome: Please see Appendix I,II

11. Likely end use : Applications in fixed wing and flapping wing UAVs and MAVs for enhancement of flight endurance

12. Details of Equipment acquired under project: Pease see **Form GR 19** (List of Equipment)

13. No. of Research staffs engaged under the project: Three

14. No. of students/researchers benefited under the project: Eight

15. No. of papers published in National conference under the project :

Under publication

16. No. of papers published in International conference under the project: ---

17. No. of papers published under the project in National Journals with impact factor: ----

18. No. of papers published under the project in International Journals with impact factor: ----

19. No. of thesis for Ph.D/M.Tech realized under the project with details: Nil

20. No. of Patents development/sealed under the project: Nil

21. Steps taken by PI for dissemination and further follow up of research work

As stated earlier the main objectives of the project are the develop a thin film solar cell-based power generation scheme, implement the scheme on typical fixed or flapping wings used in unmanned aircraft and demonstrate it in laboratory levels. This involved design, development and testing and evaluation of the modules and the assessment of the enhancement of the performance of the flapping wing, particularly in terms of the endurance. With solar power used to recharge the Li-Po cell, flapping endurance was found to increase at least by about 1minute, for usable flapping rates. Tests also showed that the enhancement in endurance is only slightly dependent on the flapping amplitude of the wing.

For further enhancement of endurance, increasing the solar output power by means of introducing power amplifier ICs can be tried. This will reduce the time duration required to charge the Li-Po cell fully. Another method to achieve is have a stand-by battery, fully charged; as the first battery gets drained, power source can be interchanged to another Li-PO cell, with solar cell array output charging the first cell. However, this could be done only after with optimization of weights and sizes, when additional components are included.

The present work, although preliminary and exploratory in nature, has provided valuable experience in the area of the development of solar film power generation on unmanned air vehicles. This experience could be utilized to design vehicles which could provide better performances, especially in the case of flappers. Design should incorporate further refinements, including optimization of solar film coating process, electronic circuit modules with optimized weights and sizes. *Further, addition of super-capacitors of suitable specifications in order to enhance the charge storage, resulting in increased flight time endurance.*

22. Suggestion, if any for further research work

a) Use of power amplifiers for further enhancement of endurance, increasing the solar output power, reducing the time duration required to charge the Li-Po cell fully.

b) Use of stand-by battery, fully charged; as the first battery gets drained, power source can be switched to a second cell with solar cell array output recharging the first battery.

c) Incorporate further refinements, including optimization of solar film coating process, electronic circuit modules with optimized weights and sizes.

d) Addition of super-capacitors of suitable specifications in order to enhance the charge storage, resulting in increased flight time endurance.

Further discussions and suggestions related to points 21 and 22 are given in Appendix III and Appendix IV.

APPENDIX I

Introduction giving the background and existing state of knowledge on the subject and the objective(s)

Keywords: Thin-film solar cell, solar film-based power generation and backup storage, flapping wing UAV/MAV, Flight endurance enhancement

1. Introduction

One of the problems faced in the development of MAVs is the short flight endurance, mainly due to the requirement of recharging the cells. This issue is particularly severe in the case of flapping wing MAVs because of the additional power requirements for flapping. In general, flight endurance of MAVs can be enhanced by improving the capability of the power source and by reducing the weight of the vehicle. To reduce the overall weight of the vehicle the power supply must be of light weight. Optimization of the overall weight of unmanned air vehicles demands the reduction of the weight and of durability of the power source.

Power sources like batteries or fuel cells used presently contribute substantially to the overall weight of the vehicles; they also require intermediate recharging which causes the deterioration of vehicle performance. A Solar film-based power source has several benefits like light-weight, coverage of higher sensing areas on the vehicle etc. Frequent recharging of power source (cells) can also be avoided. They are of considerably light-weight, can convert solar energy to electricity, leading to advantageous situations in terms of flight endurance and payload capacity.

Thin film solar cell uses an inexpensive support onto which the active component is applied as a thin coating. A thin-film solar cell (TFSC), also called a thin-film photovoltaic cell (TFPV), is a solar cell that is made by depositing one or more thin layers (thin film) of photovoltaic material on a substrate. The thickness range of such a layer is wide; it varies from a few nanometers to tens of micrometers. Many different photovoltaic materials are used, with various deposition methods on a variety of substrates. Thin-film solar cells are dz(a-Si) and other thin-film silicon (TF-Si), Cadmium Telluride (CdTe), Copper indium gallium selenide (CIS or CIGS), Dye-sensitized solar cell (DSC) and other organic solar cells.

Comparison of typical current/voltage from solar films and Li-Po batteries (Table -I) shows that solar film-based power unit can generate almost same current/voltage for an area of 0.5m^2, typical area for the proposed wing. The presently used Li-Po battery, although lighter, supplies lesser voltage for a shorter duration leading to frequent recharging. Solar thin film cells provide a constant charge, voltage and power for small air vehicles.

Type of cell/ voltage source (Typical)	**Voltage/power**
Solar panel (film type)	12V, 1100mA
Li-Po battery arrays	11.1V, 1900mAH/21.09Wh

Table I: Comparison of Voltage/power from solar films and Li-Po battery

Among the world-wide suppliers of solar thin films, *Flexsolarcells* has been identified as a possible source, who supplies a variety of flexible solar power films with accessories for OEM applications, including UAV/MAV.

The present project was initiated with the main objectives of: (a) development of power generation scheme based on thin film solar cells and storage of the solar power by means of inverter and battery, (b) implementation of the scheme on typical fixed wing and flapping wing used for unmanned mini/micro air vehicles and (c) demonstration of the scheme.

In the present work, thin-film solar cells are pasted on the surface of a typical flapping wing model. The output voltage developed across the film is tapped through electrodes, is sent to the power management (PM) module, which is controlled by a micro-controller-based airborne unit. The PM module suitably charges the battery or stores the energy accordingly. When the vehicle does the level flight or perches, the advantageous situation will be used for collecting maximum energisation of the films.

The work mainly involved (i) development of instrumentation and integration with film sensor and detailed checks of all modules (ii) initial tests and performance evaluation on a large UAV/MAV flapping wing: estimation of output power in static case, with the wings fixed and flapping case and (iii) endurance tests, without solar power (Li-Po battery only) and with replenishment of drained battery power with solar output power. It was seen that for lower flapping amplitudes of $\pm 5^o$ to $\pm 10^o$, the average solar power output power was reduced by 2%. For higher flapping angles (±30^o), however, the power reduction was found to be much reduced to bout 80% of the power at the static position of the wing. Average increase in endurance time (measured by the time for which the motor runs) were estimated to increase by about 15% at usable flapping rates of 20- 25 flapping/min.

It may be thus seen that the items power generation scheme based on thin film solar cells and storage of solar power by means of inverter and battery has been implemented successfully; a typical UAV/MAV wings with solar film power sources has been developed, tested and demonstrated successfully.

2. Previous Work Done in this or Related Fields

Research is being carried out (as part of several EC funded projects) with the aim of designing Very-Long Endurance Solar Powered Autonomous Stratospheric UAV (VESPAS-UAV) and manufacturing a solar powered prototype. This could play the role of a pseudo satellite, with the advantage of allowing a more detailed land vision due to the relative closeness to the land and at a much lower cost than a real satellite. 300km diameter area could be monitored by each of these platforms.

The mainstay at present is the silicon solar cell which accounted for 90% of the market in 2004. However these are costly to manufacture and have limited efficiency (around 14% in most production modules, and up to 25% in the lab). The cost per unit of power is at least several fold higher using silicon solar cells than that derived from fossil fuel combustion (The Institute of Nanotechnology, 2006).

A brief pictorial coverage the history of Solar energy is available in “History of Solar” by US Dept of Energy: Energy Efficiency and Renewable Energy [1]. An introductory review on Solar Arrays, Advanced Power Generation Portfolio, Multi junction Solar Cell, Advanced Array Structures and related topics is available from Merrill [2]. Lung-Jieh Yang [3] designed a full scale flexible wing frames for micro-air-vehicles (MAVs) with the wing span of 20 CMAT Tamkang University. The constructed flapping MAV Golden Snitch with a smallest body mass of 5.9g created a successful 107s flight record with a four-bar linkage driving mechanism in 2008. Augmented by the precision injection molding (PIM) manufacture, the almost polymer-made MAV with the modified driving mechanism increases the flight endurance up to 480 s in 2010. Via high speed photography, the author has ever found the wing-tip trajectory as an oblique figure-of-8 which composes the original up-and-down flapping and the induced coherent stream wise vibration while the wing beat frequency was about 10-25 Hz. Edge et al have demonstrated that greater increases in UAV performance may also be achieved through efficient and novel designs that take full advantage of the newer lightweight materials and buoyancy. Replacement of Conventional Aircraft Components with Pressurized Structures have key e key benefits of inflatable wings, increased portability and stowage and high acceleration survivability from a gun tube launch. Chen [22] in his thesis has discussed in detail the application of solar cells and new high power density batteries technology for extending the endurance, missions and capabilities of UAVs.

Siegwart [4] described that measurements of the mechanism have shown that the chosen design including the gear chain basically works well. Having four actuators, the mechanism can be used for testing different wing designs at different flapping frequencies. For a perfect design of wings, the maximum lift resulting when all four wings are flapping at maximum frequency of about 3-4 Hz, was obtained as 4.5 grams. The fact that the system produces lift is already positive, however the value of only 4.5grams is substantially too low. Compared with the total estimated weight of the MAV of 15-20 grams, it should at least produce that much lift, which is about four times as much as actually obtained in the measurement.

Noth and Siegwart [5] described the design of solar powered airplanes for continuous flight. Harris Edge et al described [6] Lighter-than-Air and Pressurized Structures Technology for Unmanned Aerial Vehicles (UAVs). Colozza [17] has observed that the amount of power available to the aircraft is based on the Environmental conditions it is flying within : Output power will vary, based on the latitude time-of year and day, a attenuation and solar cell efficiency.

Chen et al [21] have reviewed the state of the art power electronics topologies suitable for driving this wing robotic insects. Comparisons are made in the resulting configurations of MAVs across several key metrics to estimate their performance. They have also discussed the effect of performance gains in various power electronic topologies.

Air_ray, designed and developed by Fest company, is a remote-controlled hybrid construction (robot) comprising a helium-filled ballonett and a flapping-wing drive mechanism. The ballonett is a gas-tight bladder of Aluminium-vaporised PET foil with a specific mass of 22 g/qm; it can be filled with up to 1.6cbm of helium. There is a strong possibility of coating solar film on this hybrid flying robotic device.

Small robotic birds are showing lots of promise for tasks such as monitoring the environment and conducting surveillance. But one current drawback they have is the amount of time they are able to stay aloft. Because of the birds' light weight and small size, the tiny batteries used to power them deplete in just a few minutes.

University of Maryland researchers Gupta and Bruck [18-20] and their students in the Maryland Robotics Center are working on a solution that will allow longer flights and battery recharging in remote places without electrical outlets. The Clark School of Engineering team has developed and demonstrated a new version of its *Robo Raven* micro air vehicle (MAV) that incorporates solar panels in its wings. While the solar panels do not yet produce enough energy to power Robo Raven III in flight (they produce around 3.6 Watts while *Robo Raven* needs around 30 Watts to fly), they are effective in charging the MAV's batteries when it is stationary. Gupta notes that the development team envisions *Robo Raven* flying "far away from civilizations" during long missions and needing "a way to 'feed' itself" on its journeys. Because *Robo Raven's* large wings have enough surface area to create a usable amount of solar energy, the team decided to incorporate flexible solar cells into them. The captured solar energy is then used to supply Robo Raven's on-board batteries.

Oraibi et al [23] proposed a hybrid battery charging system along with the charging process with time for the rechargeable battery to co-ordinate the utilization of renewable energy supply to charge battery and reduce the charging time for the battery. Reliability and battery charging time were applied to evaluate the electric energy storage and renewable energy resource integration and the discharge of the batteries that is resulted from the leakage current. The result of case studies explain the benefits of the operation strategies and produce insights explain how electric energy storage capacity of the battery, limited power capacity impact on the reliability and battery charging time. Amoiralis et al [24] have provided provides an overview of the research conducted on the field of UAV energy efficiency optimization. The authors showed that achieving energy efficiency onboard the UAV can be through optimization of mission waypoints, use of a Hybrid-Electric Propulsion System onboard the UAV and use of effective power management systems.

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APPENDIX II

Experimental work and Analysis of Results

1. *Experimental methods and procedure*

As mentioned earlier, the present work was initiated with the main objective of the developing a power generation scheme based on thin film solar cells and storage of the solar power by means of inverter and battery. As the solar films have to be pasted on to the surface of a flapping wing, thinnest available films with the best efficiency had to be used. After detailed survey of the available films in the market, thin Film Solar Cells *(SKU: SolMaxx-Flex-4_8V100mA*) made by *Silicon Solar Inc., USA* was procured. This film has typically a maximum output voltages and currents respectively of V_{oc}=6.4V, I_{sc}=120mA respectively, with average values of voltages, current and power, V_m=4.8V; I_m=100mA & P_m=0.48 W. Flexibility of the film is also found to be good.

A brief description of the experimental activities in the project and their status are given in Table II. After the procurement flexible solar films and accessories, Li-Po batteries, electronic components and modules for the development of the power source, the subsystem modules were designed, developed and tested. Flapping wing model, *Hobby King/Spy Bird Eagle Ornithopter,* Model No.569000001-0/48486 (Wingspan: 1200mm; CHORD 218 MAX 200, Avg length: 700mm), BLDC motor (*Robodo Electronics A2212/13 KV1000 Brushless Motor BLDC Hex Rotor Multicopter*) and Brushless Speed Controller with BEC ESC (*Folksrc 30A*) were procured.

A block schematic of the set up for initials tests is shown in Fig.1 and Fig.2. A set of 12 films (SolMaxx-Flex-4_8V100mA, 2 in series, 3 in parallel) were pasted on the surface of fixed wing MAV (450mm span NAL Golden Hawk), as shown in the Figs.1 and 2. For better distribution of solar cells on the wing area and easiness of connection, six single flexible films (94mmX150mm), shown in Fig.3(a), was cut in two and were joined together in series, as shown in Fig.3(b). Resulting o/p voltage is 12.8V and current of 6X120mA =720mA. Resulting o/p power = 9.216W. In order to get a steady, fluctuation-free Solar power, it was taken out through a Solar Charge Converter/Controller (*Silicon Solar, SKU – True Power-CContr-12V4A*). The output was measured with precision multimeter and an oscilloscope. A steady output of 12.8VDC with ripple much less than 5mV (shown in Fig.1) was obtained respectively. *It may be noted that the NAL Golden Hawk fixed wing model was used a* *starting point, since its wings provided good rigid surface for pasting the films, avoiding uncertainties like wrinkles, free of the unevenness of the pasted films.*

<table>
<tr><th colspan="2">ACTIVITY</th><th>STATUS</th></tr>
<tr><td colspan="2">Selection of suitable thin solar films and procurement of materials</td><td>Completed</td></tr>
<tr><td rowspan="5">Development of instrumentation and integration with film sensor</td><td>Procurement of Li-PO and ion cells, solar charge converter/controller, BLDC motor, associated electronics</td><td>Completed</td></tr>
<tr><td>Development of switching circuits and logic for charge control and feedback motor control</td><td>Completed</td></tr>
<tr><td>Wing assembly, populating wing with flexible solar films, connections and o/p power measurements</td><td>Completed</td></tr>
<tr><td>Detailed Checking of all individual modules</td><td>Completed</td></tr>
<tr><td>Integration of all modules</td><td>Completed</td></tr>
<tr><td rowspan="2">Initial tests and Performance evaluation on a large UAV/MAV flapping wing: static case</td><td>O/p power check, no load, static cases & flapping</td><td rowspan="4">Completed</td></tr>
<tr><td>Endurance check (motor running): static cases without solar Endurance check (motor running): static cases without solar backup charging</td></tr>
<tr><td rowspan="2">Performance evaluation on UAV/MAV wing flapping @ low freq. (1,2,3,4,5 Hz)</td><td>Endurance check (motor running): static cases– with solar backup charging & comparison with Endurance check (motor running): static cases – with solar backup charging</td></tr>
<tr><td>Endurance check with flapping

Endurance check with flapping: with solar backup charging</td></tr>
<tr><td colspan="3">Data analysis and documentation : Results analyzed ; advantage of using solar power back up brought out</td></tr>
</table>

Table II : List of Experimental Activities and Status

Circuits for switching logic for charge control and feedback motor control were developed. These modules are shown in the block schematic in Fig.4. Output from the solar films pasted on the wing surfaces is connected to a solar charge converter/controller, which provides a steady ripple-free DC output. The controller also ensures the operation of the cells lose to the peak efficiency. A Li-Po battery supplies necessary power to the Brushless DC (BLDC) motor and ESC (electronic speed controller). The power controller module, shown in the figure, controls the charging of the battery when the charge falls below selected level. The battery can also be operated in the continuous charging mode. Transfer of all the relevant data and operation of modules are achieved using the microcontroller board and the PC system, shown in Fig.4.

Fig.5 shows *Flapping Wing* mechanism and Fig.6 the flapping wing model. Flexible solar films are fixed on the flapping wing and the tail, as shown Fig.7. 12 pairs of films are pasted on the flapper, giving an output voltage of 12.8V at a current of 1440mA, with a total power output of 18.43 watts. Two solar modules are kept on the tail of the flapper. It is to be noted that the tail is also positioned horizontal (in the same plane as wing), which will not be flapping. The solar power output estimated in the flapping case is actually with two of the films fixed.

Output from the integrated solar film array is measured using the above setup.

Details of the effective areas of solar films are given below.

Wing span: 1200mm, Chord : maximum 218mm, MAC :200mm,

Number of films pasted on wing : 12; On tail : Length:150mm, Number of films on tail : 2

Effective Solar sensing area (i) on wing: 150mmX94mmX10 = 141000mm^2, (ii) on tail: 150mmX94mmX2= 28200mm^2

A simple schematic of O/P power variation measurement with angle changes is shown in Fig.8. The setup consists of mechanical devices for varying and measuring the incidence angle of the wings, power meter to measure the o/p voltages for different incidences. Two angular positions of the wing (separated by angle, ϕ) are shown in two different colours. Output power corresponding to each angle is measured using a precision digital multimeter.

2. Analysis of Results

As mentioned earlier, tests on the evaluation and performance of the solar film based power source involved initial tests and performance evaluation on a large UAV/MAV flapping wing wherein output powers from the film array were measured in static case, with the wings positioned at different angles and wings flapping. Estimations of the flight endurances were made in terms of motor running time, without solar power (Li-Po battery only) and with replenishment of drained battery power by solar film output power. Results of these exercises are discussed n the following sections.

2.1 Solar output power variation with variation of wing angle

Incidence Angle, ϕ^o	O/p power Measured, Watts	Incidence Angle : ϕ^o	Calculated O/p power based on Area reduction: $A.\cos\phi$
0	15.36	0	15.362
5	15.30148	2	15.35265
10	15.12653	4	15.32462
15	14.83622	5	15.3036
20	14.43364	6	15.27793
25	13.92077	8	15.21265
30	13.30176	10	15.12885
45	10.85952	12	15.02664
		14	14.90614
		15	14.83908
		16	14.7675
		20	14.43649
		25	13.92414
		30	13.30592
		35	12.58654
		40	11.77147
		45	10.8669

Table III : Comparison of O/p power variation w.r.t. wing incidence:
Calculated and measured values

After the qualitative and quantitative evaluation of output power from the solar film arrays, estimation of the output power variation was carried out, with the wings positioned at different angles (0^o to 45^o). *These measurements were made in the mid-noon (after 12PM) in order to reduce the uncertainties due to sunrays falling at angles at horizontal positions of the wings.* Results of the output power variation are shown in Table III. Calculated power is obtained from the reduced area (***A***) of illumination, in terms cosine law, I.e., ***A*** and ***A.cosΦ***.

Solar output power data shown table and in the graph are for 10 solar films, pasted on the wing, undergoing changes in the angular position. The total solar output power, including that from the tail (2 pairs of films), is 18.432 Watts. Thus, the solar power o/p from the wing at horizontal position is thus 18.432watts - 3.072watts (from tail) = 15.36 watts.

A comparison of the above is also graphically in Fig.9. As can be seen from the Table and Fig.9, there is very close agreement between calculated and measured powers. Reduction in the output power is ~30%, even at a large angle of 45^o.

2.2 Flapping Endurance

a) Solar Power output variation

As mentioned earlier, it is important to make an estimation of the effective power available from the solar film array for charging the Li-Po cell and the flapping endurance (an indicator of flight endurance). For this purpose, the wings were flapped at different amplitudes, ranging from $\pm 5^o$ to $\pm 30^o$. Table IV shows the variation solar power output for varying amplitudes of flapping.

Flapping Amplitude (Deg)	Solar power o/p (W)	% power reduction
0	18.4320	0
±5	18.1504	1.53
±10	17.7920	1.94
±15	17.3184	2.57
±20	16.6912	3.40
±25	15.9488	4.03
±30	12.9638	16.19

Table IV : Solar O/p power variation with varying flap amplitudes

Fig.10 shows the plot of the above variation graphically. While the reduction in power is small at lower amplitudes of flapping, it can be seen that here is higher power reduction at higher flapping amplitudes; power reduces by ~16% the wing flaps between $+30^o$ to -30^o.

b) Variation of flapping endurance w.r.t. flapping rates with Solar Power backup

Flapping rate (flaps/min.)	Endurance of flapping, without solar backup, mins	Endurance of flapping, with solar backup, mins	Enhancement in endurance (mins)
25	5.205	5.953	0.748
20	6.507	7.664	1.157
15	8.676	10.700	2.024
10	13.014	17.465	4.451
5	26.027	43.311	17.284

Table V: Variation of flapping endurance w.r.t. flapping rates with and without solar power backup

In order to estimate the duration for which the wing can flap continuously till the battery gets drained, tests were conducted with the flapper fixed and the wing flapping. Table V shows the results of the tests. It can be seen that the battery can be used continuously only for 6.57 mins at a realistic flapping rate (in which the flapper can fly) of 20 flaps/min. With the solar output continuously recharging the battery, this duration is found to increase to 7 minutes. At lower flapping rates, the increase in duration is found to be better. Above

The above data is presented graphically in Fig.11. It can be seen that the battery (without solar power backup) scan be used continuously only for 6.51mins and 5.21mins respectively, at practically usable flapping rates (in which the flapper can fly) of 20 and 25 flaps/min. With the solar output continuously recharging the battery, this duration is found to increase by 1.157 and 0.75 min. At lower flapping rates, there is much better enhancement; however, flapping rates below 5 flaps/mins.

With further optmisation in film pasting, electronic design etc., flapping endurance could be further enhanced.

For further enhancement of endurance, increasing the solar output power by means of introducing power amplifiers can be tried. This will reduce the time duration required to charge the Li-Po cell fully. Another method to achieve is have a stand-by battery, fully charged; as the first battery gets drained, power source can be switched interchanged, with solar cell array output charging the first battery. However, this could be done only with optimized weights and sizes, when additional components are included. Further, addition of super-capacitors of suitable specifications in order to enhance the charge storage, resulting in increased flight time endurance.

Fig.1 : Solar film test set up

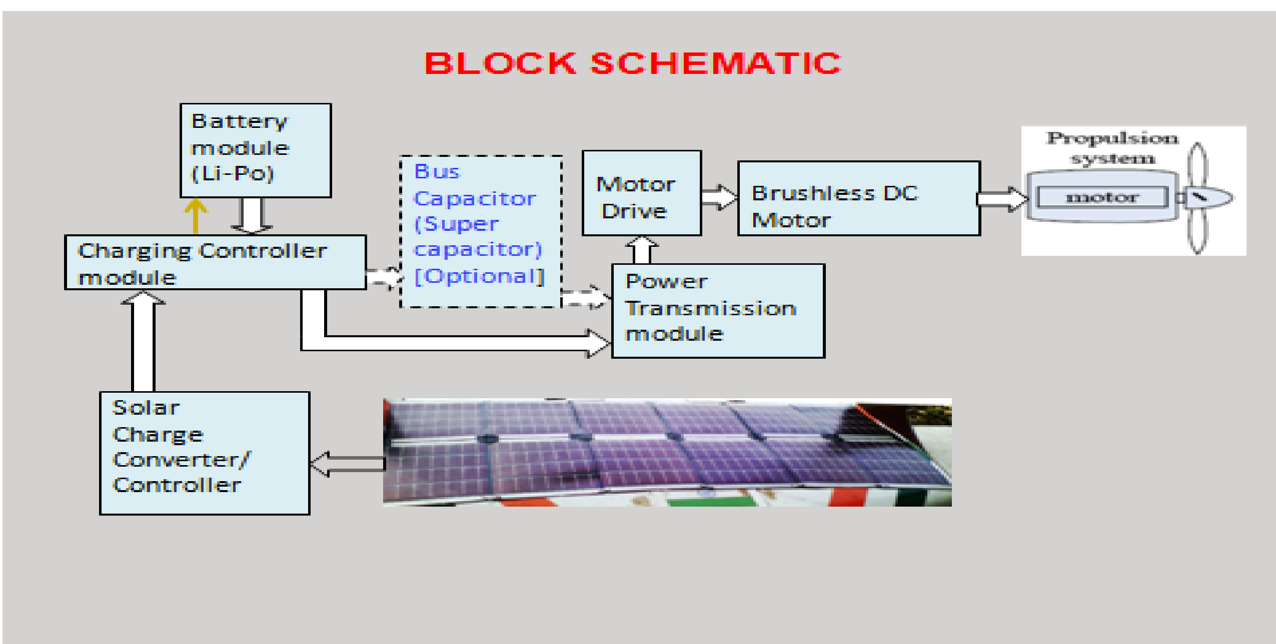
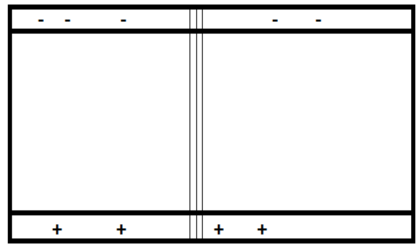
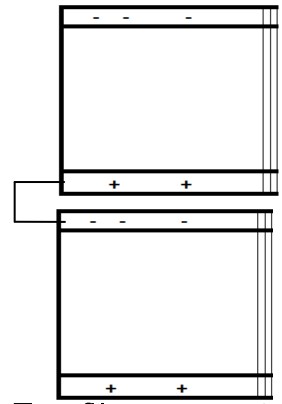


Fig.2 : Validation set up for power source with film on FW-MAV



(a) Original film (double) – 6.4V@ 120mA



b) Two films connected in series, O/P:12.8V@120mA

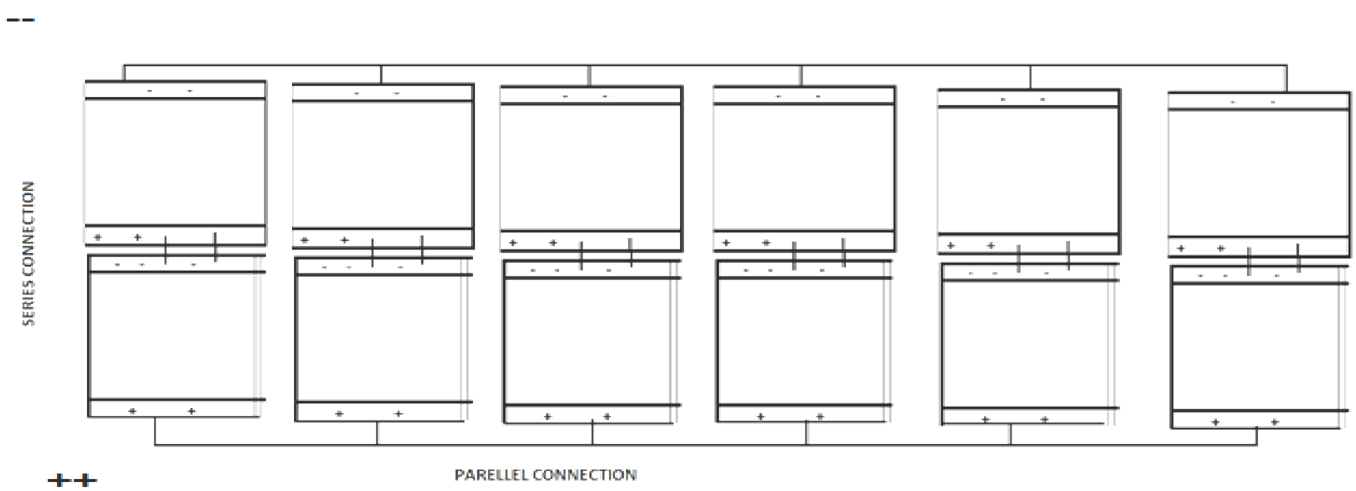


Fig.3: Solar film array configuration

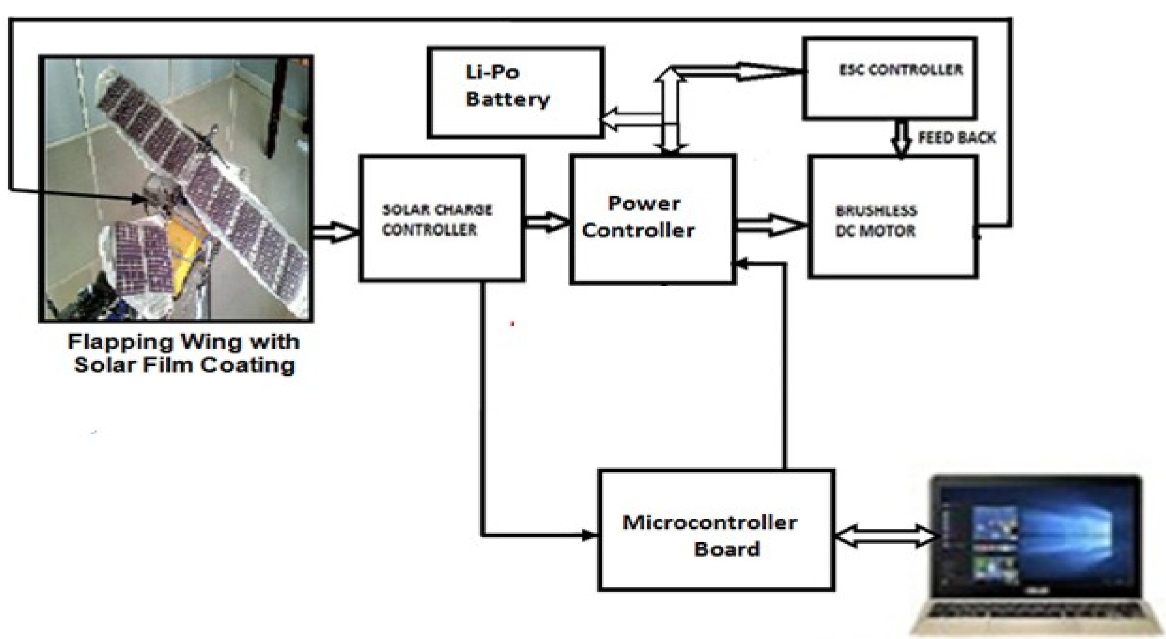


Fig.4 : Block schematic of power source with controller an data acquisition modules

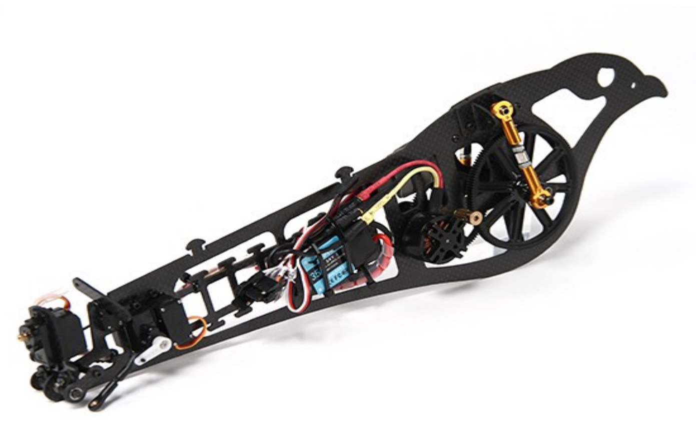


Fig.5: Flapping Wing mechanism

Fig.6: Flapping Wing

Wing span: 1200mm, Chord :max 218mm, MAC :200mm,Tail:150X94mm2, Drive - Motor: BLDC

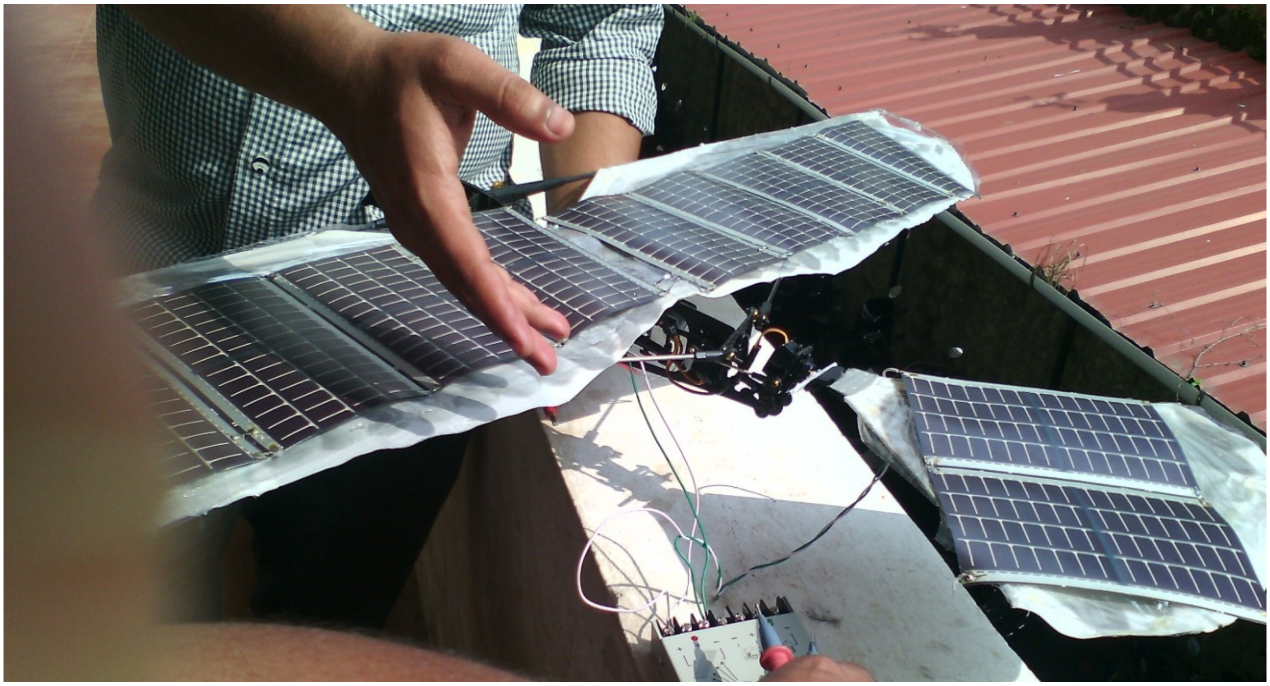


Fig.7: Fixing flexible solar films on flapping wing

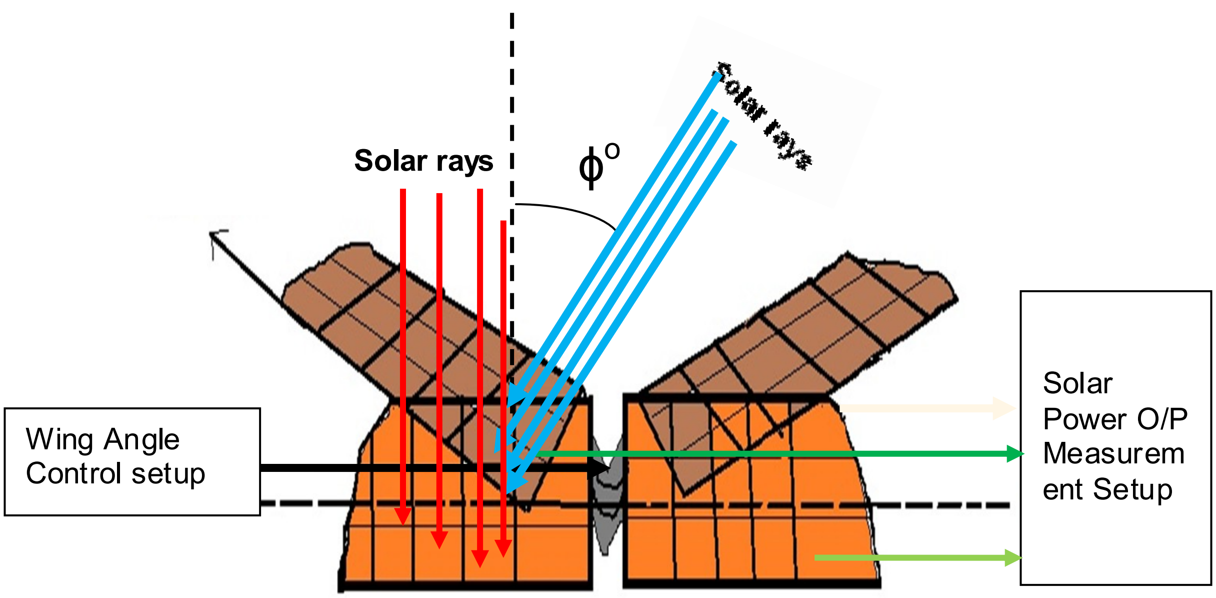


Fig.8: Setup for measurement of O/P power variation w.r.t wing angle changes

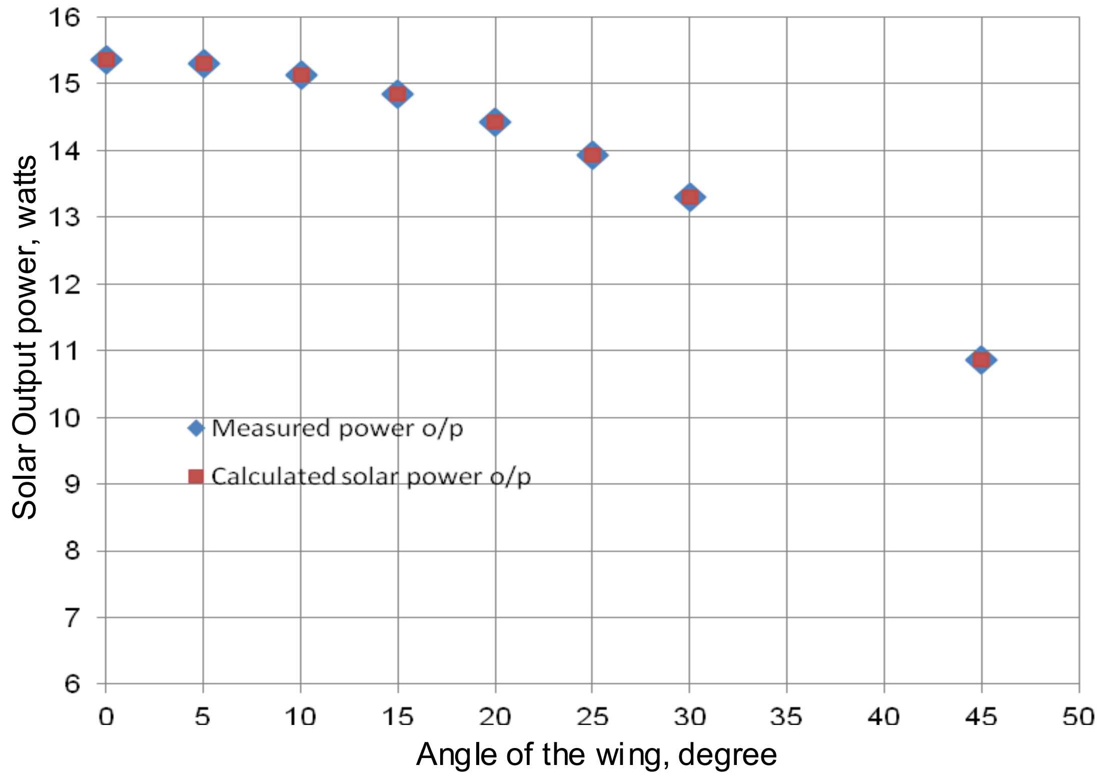
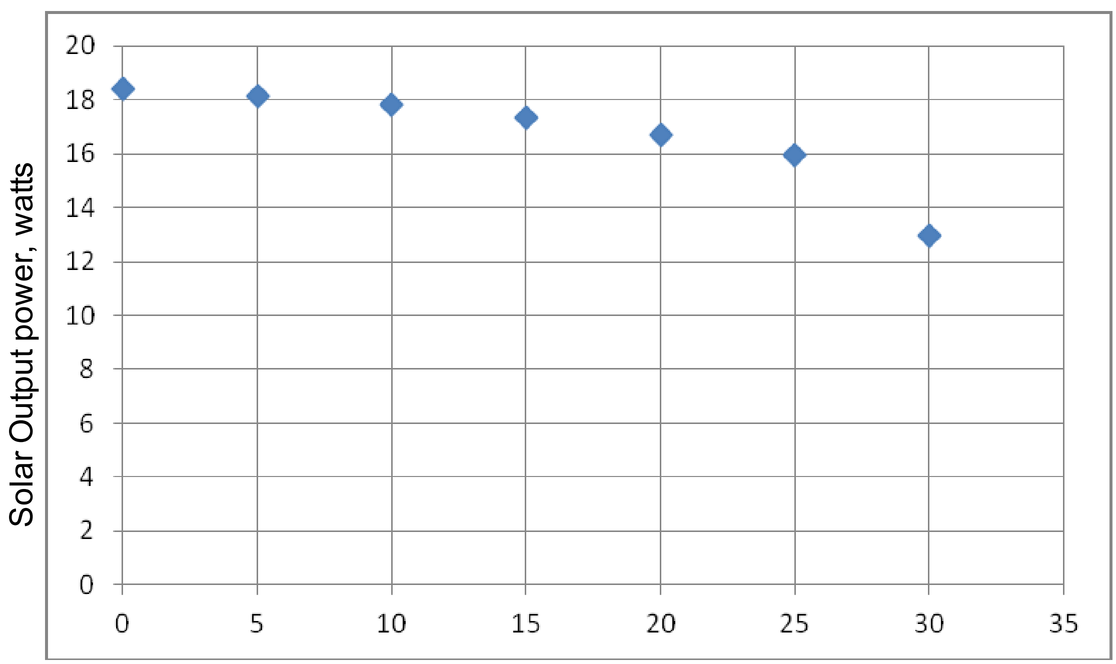


Fig.9 : Variation of Solar film O/P power with Incidence Change
Static Case): Comparison with calculated data from cosine relation



Flapping amplitude (In terms of degrees)

Fig.10 : Variation of Total Solar film O/P power with flapping

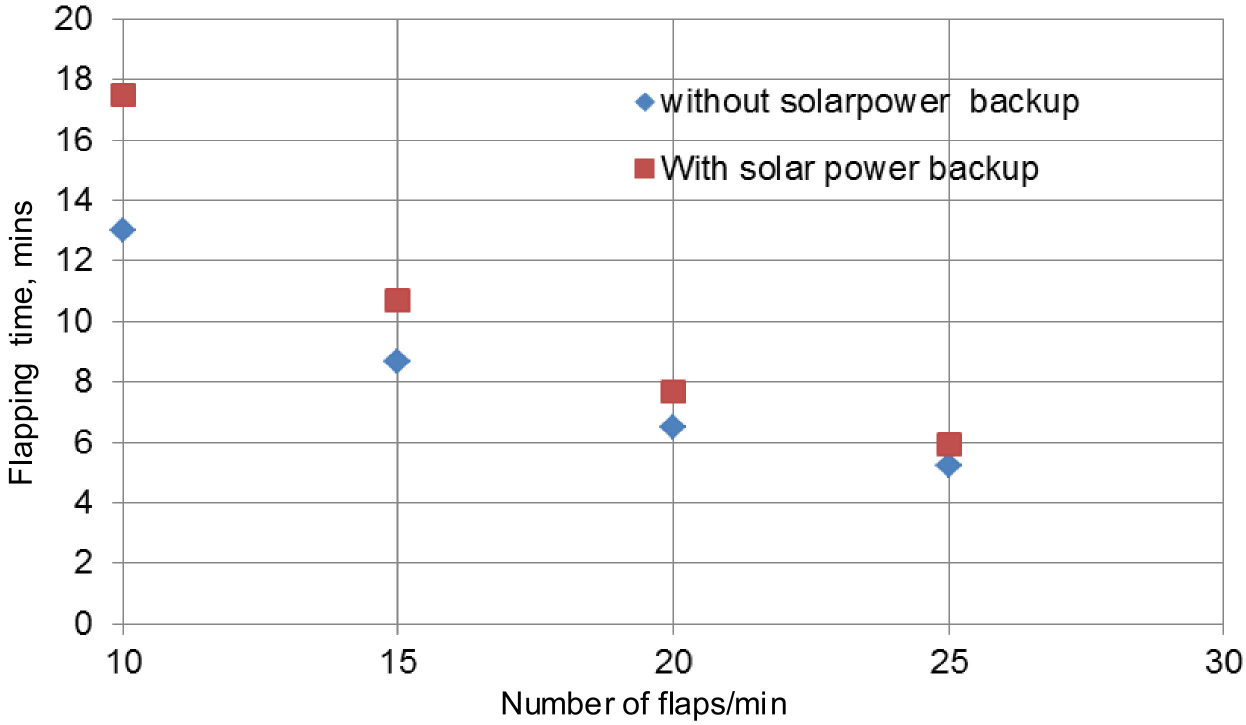


Fig.11 : Variation of flapping endurance without and with solar power backup

APPENDIX III

Conclusions giving the achievement with Reference to the main objective(s)

As mentioned earlier, it is extremely important to enhance the flight endurance times of fixed wing/flapping wing UAVs and MAVs for their efficient and effective performance in their crucial mission applications. Power sources for these classes of flying vehicles are based on batteries like Li-Po, Li-ion etc. These power sources have limitations in terms of the storage of charge, which result in reduced endurance, particularly in the case of flapping wing UAVs/MAVs. Under such situations, application of thin, flexible solar films to generate power, which can supplement the power from battery, is a viable alternative. The present work was initiated with the basic objectives of design and development of a solar film based power source and its application in enhancing the performance of fixed or flapping wing air vehicles.

After procurement and initial tests of suitable thin solar film cells, the films were pasted on the upper surfaces of a fixed wing (NAL Golden Hawk model) and a flapping wing UAV wings and tail. Necessary electronic circuits and modules were designed and developed for solar charge conversion and control, charging cycle control and the acquisition and storage of data from laboratory level and field data. After the necessary validation and tests of the integrated modules and the cells, the solar cell performance was evaluated under static and flapping conditions of the wing, under different flapping angles and frequencies. It was found that with increasing incidence angles, reduction in the output power is ~25%, even at a large angle of 45^o in the static case.

Reductions in the solar output power is small at lower amplitudes of flapping. However it was seen that here is higher power reduction at higher flapping amplitudes; power reduces by ~16% the wing flaps between $+30^o$ to -30^o. Endurance tests were carried out (with the flier fixed and wings flapping) for all the above cases. With solar power used to recharge the Li-Po cell, endurance was found to increase by 1.157 and 0.75 min. for 25 flapping/min and 20 flapping/min. respectively. For further enhancement of endurance, increasing the solar output power by means of introducing power amplifiers can be tried. This will reduce the time duration required to charge the Li-Po cell fully. Another method to achieve is have a stand-by battery, fully charged; as the first battery gets drained, power source can be switched interchanged, with solar cell array output charging the first battery. However, this could be done only after with optimized weights and sizes, when additional components are included.

The work, although preliminary and exploratory in nature, has provided valuable experience in the area of the development of solar film power generation on unmanned air vehicles. This experience could be utilized to design vehicles which could provide better performances, especially in the case of flappers. Design should incorporate further refinements, including optimization of solar film coating process, electronic circuit modules with optimized weights and sizes. Further, addition of super-capacitors of suitable specifications in order to enhance the charge storage, resulting in increased flight time endurance.

It may be thus seen that the items power generation scheme based on thin film solar cells and storage of solar power by means of inverter and battery has been implemented successfully; a typical UAV/MAV wings with solar film power sources has been developed, tested and demonstrated successfully.

APPENDIX IV

Abstract highlighting the salient features of the Work

Enhancing flight endurance times of fixed wing/flapping wing UAVs and MAVs for improved performance during critical crucial missions is an important aspect of unmanned vehicle development. Since power sources for these flying vehicles have limitations in terms of the storage of charge, which result in reduced endurance, power sources based on flexible solar films supplement the power from battery, is a viable alternative. The present work was initiated with the aims of developing a power generation scheme based on thin film solar cells and storage of the solar power by means of inverter and battery, implementation of the scheme on typical fixed wing and flapping wing used for unmanned mini/micro air vehicles and demonstration of the scheme. The work mainly involved development of instrumentation and integration with film sensor and detailed checks of all modules, initial tests and performance evaluation on a large UAV/MAV flapping wing; estimation of output power in static case, with the wings fixed and flapping case and endurance tests, without solar power (Li-Po battery only) and with replenishment of drained battery power with solar output power. After procurement and initial tests of suitable thin solar film cells, the films were pasted on the upper surfaces of a fixed wing (NAL Golden Hawk model) and a flapping wing UAV wings and tail. Necessary electronic circuits and modules were designed and developed for solar charge conversion and control, charging cycle control and the acquisition and storage of data from laboratory level and field data. After the necessary validation and tests of the integrated modules and the cells, the solar cell performance was evaluated under static and flapping conditions of the wing, under different flapping angles and rates.

The output voltage developed across the film is tapped through electrodes, is sent to the power management (PM) module, which is controlled by a microcontroller-based airborne unit. The PM module suitably charges the battery or stores the energy accordingly. When the vehicle does the level flight or perches, the advantageous situation will be used for collecting maximum energisation of the films. Endurance tests were carried out (with the flier fixed and wings flapping) for all the above cases. With solar power used to recharge the Li-Po cell, endurance was found to increase by 1.157 and 0.75 min. for 25 flapping/min and 20 flapping/min. respectively.

It may be thus seen that the items power generation scheme based on thin film solar cells and storage of solar power by means of inverter and battery has been implemented successfully; a typical UAV/MAV wings with solar film power sources has been developed, tested and demonstrated successfully.

The above work, although preliminary and exploratory in nature, has provided valuable experience in the area of the development of solar film power generation on unmanned air vehicles, interfacing ad control for supplementing with primary power source and performance enhancement. This experience could be utilized achieve better performances by design and development of systems incorporating refinements, including optimization of solar film positions, coating process, electronic circuit modules with optimized weight s and sizes. Further, addition of super-capacitors of suitable specifications in order to enhance the charge storage, resulting in increased flight time endurance.

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