Imperial College London

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Preliminary design of a solar sail propelled spacecraft for extrasolar trajectories

Interim oral presentation

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Context and Motivation

- Prior extrasolar missions:
  - Voyager I and II
  - Pioneer 10 and 11
  - New Horizons

- Notable prior solar sailcraft:
  - IKAROS
  - LightSail 1 and 2 (3U CubeSat)

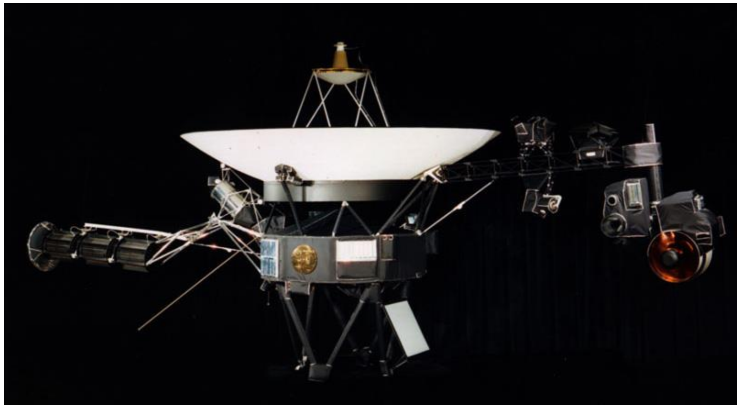
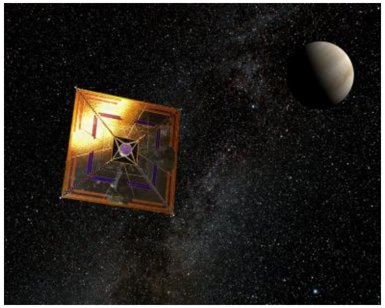
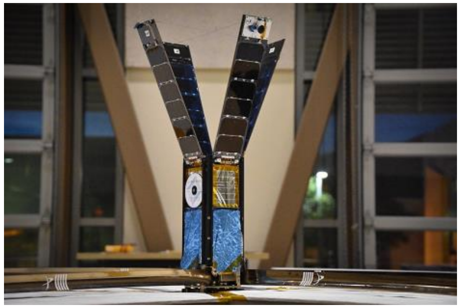


Photo taken of Voyager assembled [1]



Artist depiction of IKAROS [2]



LightSail 2 after boom deployment test [3]

[1] https://voyager.jpl.nasa.gov/assets/images/galleries/images-of-voyager/spacecraft_profile.jpg [2] https://commons.wikimedia.org/wiki/File:IKAROS_solar_sail.jpg
[3] http://www.planetary.org/multimedia/space-images/spacecraft/lightsail-2-ground-finale.html

Project Objectives

Primary Objectives:

- To launch a solar sailcraft to exit the Solar System within 100 years to maximise its scientific utility
- To carry out measurements of the sailcraft’s trajectory and produce a method of designing larger-scale extrasolar missions

Secondary Objectives:

- To produce a high-TRL solar sailcraft
- To advance CubeSat capabilities
- To attract funding for CubeSat development in subsequent years
- To establish Imperial College London as leader for CubeSats within UK and an innovator in space technologies worldwide

Background information

Progress from the previous papers

Previous work – Feasibility study [4]

- Identified candidate trajectories within constraints
  - Particular focus on using kick burn injection to gain ideal orbit

- Initial system sizing
  - Sail sizing
  - Candidate materials for sail (e.g. Mylar, CP1, Kapton)
  - Passive communication system*
  - Mass budget

- Proved the proposed mission was feasible and within remits of university research, using current technologies

[4] Hotston-Moore, E. (2019) Feasibility analysis of a solar sail propelled spacecraft for extrasolar trajectories

Previous work – Preliminary design [5]

- Utilised GMAT to perform orbital propagation simulations
- Demonstrated feasibility of sailcraft deployment and injection without kick burn on a Mars transfer orbit
- Refined bounds of feasibility for chosen reference trajectory through a number of studies
- Updated reference case trajectory
- Provided design envelope for future work

[5] Geragidis, F. (2021) Preliminary design of a solar sail propelled spacecraft for extrasolar trajectories

Previous work – Preliminary structural design [6]

- Preliminary structural model for spin-stabilised and boom deployment design concepts, modelled in ABAQUS

- Wrinkling analysis and effect on performance

- Proved passive tracking to be unfeasible due to prior miscalculations
  - Gave starting point for calculations on active tracking TT&C and power subsystem options

[6] Montete, P. (2021) Preliminary structural design of a solar sail propelled spacecraft for extrasolar trajectories

FYP Objectives

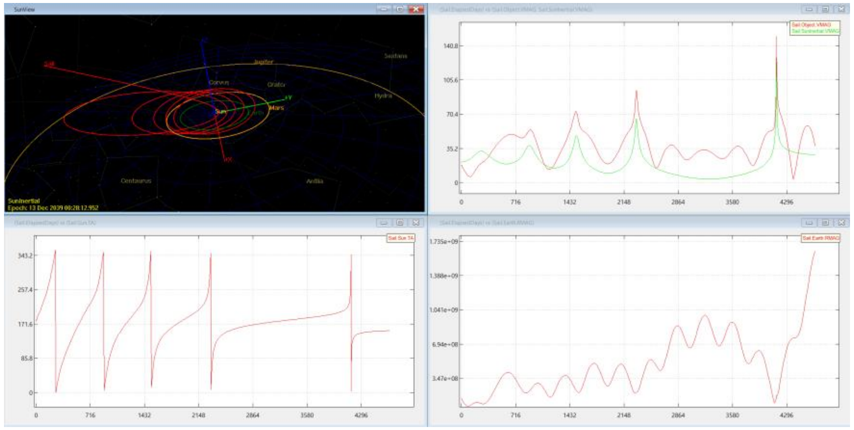
1. Update sizing and budgets of the solar sailcraft
    1. Define requirements for TT&C and Power subsystems
    2. Create updated design envelope and mass budget

2. Define additional reference cases with consideration of design envelope

3. Orbital Perturbation Study to validate reference cases

Current Progress

- Familiarised with previous papers in the project and surrounding material
- Familiarised in using GMAT
  - Ran sample missions
  - Explored GMAT file from past work
- Identified parameters to use in simulations for simulations from end of Geragidis paper [5]
  - Past studies ran simulations using sail area of 454 m²



Simulation of reference case in GMAT using up-to-date parameters

Parameter	Minimum	Design	Maximum	Units
A_{sc}	7.6	**12.4**	28.6	m^2
A_s	7.5	**12.2**	28.3	m^2
a_{sc}	2.76	**3.52**	5.35	m
$r_{sc_{stowed}}$	0.35	**0.44**	0.67	m
m_{sc}	0.069	**0.087**	0.146	kg
m_{cr}	3.178	**4.681**	9.790	kg
m_f	0.694	**1.129**	2.610	kg

System sizing from design envelope [5]

[5] Geragidis, F. (2021) Preliminary design of a solar sail propelled spacecraft for extrasolar trajectories

Future Work

Subsystem Sizing

- Run reference case within min/max limits of design envelope
  - To confirm 10 AU limit for tracking
- Calculate TT&C requirements
- Find power requirements
  - daily/weekly/monthly reporting
- Update mass budget for sailcraft and carrier accordingly
  - For both design concepts (spin vs boom)
- Assess feasibility of expanding payload if excess mass available
  - Increasing potential scope of mission increases scientific utility

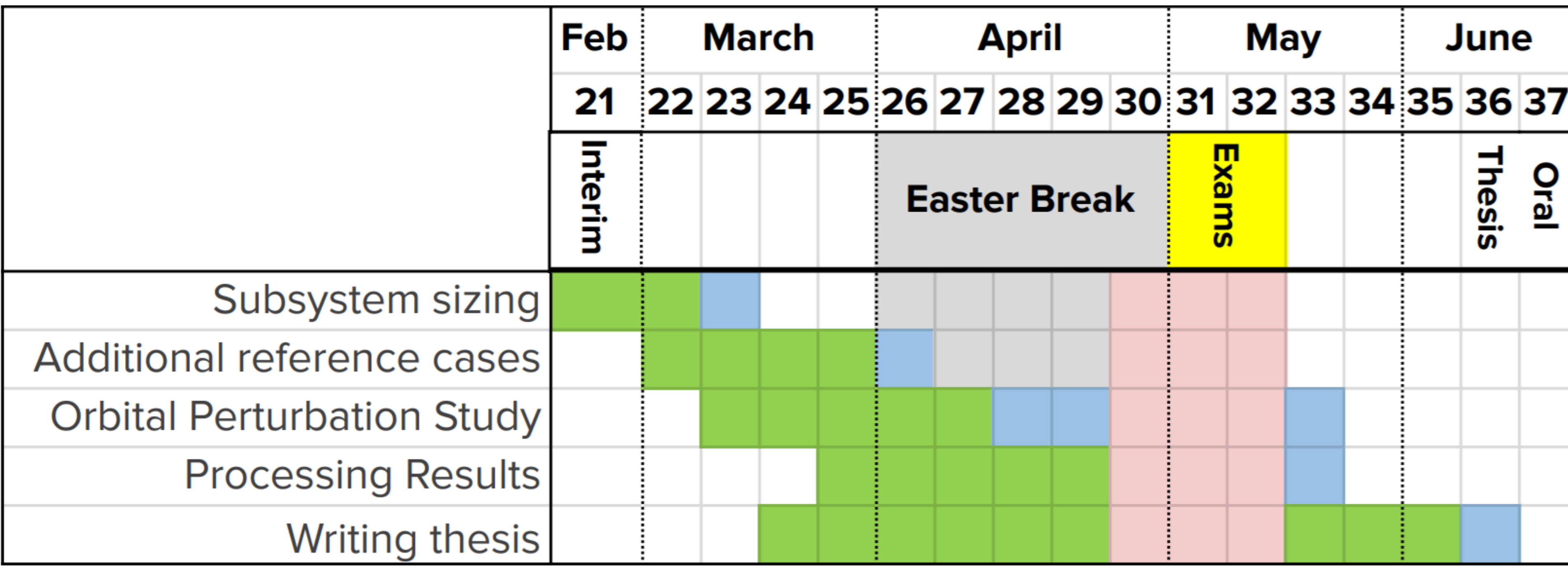
Additional reference cases

- Current reference case uses February 2027
  - Very soon in scope of project timeline
- Need for more launch opportunities to be assessed
- Explore direction of escape trajectory relative to launch window
  - Ability to targeting certain directions may be beneficial for interstellar scope in future missions (e.g. Alpha Centauri)
  - If certain launch windows allow planetary flyby, could benefit from additional instrumentation
    - Planets up to Saturn are within 10 AU

Orbital Perturbation Study

- Create model for Attitude Dynamics to assess stability in orbital perturbation
  - Code in MATLAB
  - Input: Propagation and SRP data from GMAT, initial spin condition
  - Output: Time-step of attitude dynamics (position and angular vectors)
- Vital in scope of mission to truly validate reference cases
- Current mission relies on passive stabilization
  - If spin is destabilised, sailcraft will not be able to adjust orbit effectively or even at all → mission failure
  - Could affecting wrinkling of spin-stabilised design
    - Would require further analysis in future paper
- If reference cases cannot be validated, trajectories need to be re-evaluated from scratch alongside design changes

GANTT Chart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Interim
Easter Break
Exams
Thesis
Oral
Subsystem sizing
Additional reference cases
Orbital Perturbation Study
Processing Results
Writing thesis