Space Legos: A Concept for In-Space Assembly of Large Structures with a Stationary Robot

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ABSTRACT

Human nature is inherently driven by the desire to build; advancing from primitive shelters to skyscrapers, and extending this relentless pursuit of progress to space through technological innovations. As space missions require larger and more complex structures, traditional deployable systems face challenges due to constraints on launch mass, volume, and complex deployment mechanisms. In-space assembly (ISA) offers a promising solution for constructing large structures, such as telescopes and satellites, directly in space.

This thesis introduces a novel ISA concept with a centralized ‘truss builder’ for autonomous assembly of polygonal-ring structures, using simple, repetitive operations and focusing on scalable mesh reflectors for communication and imaging. Utilizing the standard AstroMesh architecture, a rapid generalized design method is developed. Through the analysis of reflector geometry, optimized cable prestress, structural design, and a high-fidelity finite element model, analytical scaling laws are derived for mass, stowed envelope, and natural frequency based on aperture diameter. A semi-analytical homogenization model is introduced to efficiently predict fundamental natural frequencies. Stowed volume is a key limitation for large deployable reflectors, approaching current and future launch capacity limits, while the proposed ISA reflectors face no such constraints for apertures up to 200 meters.

A two-dimensional finite element model simulates the assembly kinematics of large ring-like structures with the proposed ISA concept, enhancing understanding of the process and evaluating key design aspects of a stationary robot assembling scalable ring-like trusses. The model provides insights for optimizing autonomous assembly systems and underscores the need for advanced numerical simulations to ensure smooth assembly and stability during ISA, especially as structures scale.

Lab-scale prototype testing validates the ISA concept, with results aligning qualitatively with simulations. Both experiments and simulations reveal a range of viable solutions, demonstrating flexibility for future mission designs. This research offers crucial insights into the design and scaling of mesh reflectors, setting the stage for comparing ISA with traditional deployable systems. The proposed ISA concept presents a practical solution for building high-precision, large-scale structures in space, advancing the field of space construction and supporting future extended space missions.

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TABLE OF CONTENTS

Acknowledgements iii
Abstract v
Published Content and Contributions vi
Table of Contents vii
List of Illustrations x
List of Tables xv
Nomenclature xvi
Chapter I: Large Structures in Space 1
  1.1 In-Space Assembly: A Strategy for Launching Large Space Structures? 1
  1.2 Robotic Autonomous Assembly 3
  1.3 Reflector Antennas 6
  1.4 Feasibility of In-Space Assembly Concepts 8
  1.5 Thesis Outline 8
Chapter II: Establishing the Limits of Deployable Reflectors 11
Article: Scaling Laws for Deployable Mesh Reflector Antennas
  2.1 Motivation 12
  2.2 Geometry, Connectivity, and Prestress 14
    2.2.1 Geometry and Design for Kinematic and Static Determinacy 14
    2.2.2 Prestress Optimization of Cable Nets 17
    2.2.3 Potential Modifications to the Minimum Tension Requirement 20
  2.3 Structural Design 22
    2.3.1 Metallic Mesh and Cable Net Design 22
    2.3.2 Perimeter Truss Design 22
    2.3.3 Joint Design 23
  2.4 Scaling of Mass and Volume 25
    2.4.1 Estimating Mass and Stowed Volume 25
    2.4.2 Mass and Stowed Dimensions Results 26
    2.4.3 Analytical Scaling Laws 27
    2.4.4 Scaling Studies for Deeper Reflectors 29
  2.5 Scaling of Natural Frequencies of Vibration 31
    2.5.1 Finite Element Model and Boundary Conditions 31
    2.5.2 Natural Frequencies and Mode Shapes 32
    2.5.3 Semi-Analytical Models for Fundamental Frequencies . . . 34
  2.6 Chapter Conclusions 39
Chapter III: ISA Concept for Ring-Like Structures 41
  3.1 Motivation 42
  3.2 Scaling of Mass and Stowed Volume for ISA Reflectors 43
  3.3 In-Space Assembly Concept 45

    3.3.1 General Overview 45
    3.3.2 Operations of the Truss Builder 47
  3.4 Chapter Conclusions 49
Chapter IV: Simulation of ISA Concept 50
  4.1 Motivation 51
  4.2 Numerical Simulation Setup 52
    4.2.1 Model Definition 53
    4.2.2 Modeling the Cable Net 54
    4.2.3 Simulation Steps 56
  4.3 Tuning the Simulation for a Six-Sided Structure 59
    4.3.1 Angle Stops 59
    4.3.2 Assembly Plate Orientation 60
    4.3.3 Damping Coefficients 61
  4.4 Simulation Results for the Six-Sided Structure 62
  4.5 Chapter Conclusions 65
Chapter V: Simulation of Twelve-Sided Reflector 67
  5.1 Motivation 67
  5.2 Effect of Assembly Plate Orientation 68
  5.3 Effect of Prestressing Method 70
  5.4 Effect of Cable Net Orientation 72
  5.5 Further Considerations for Assembly Simulation 75
    5.5.1 'Jamming' Condition 75
    5.5.2 Cable Activation and Bay Release Sequence 75
    5.5.3 Prestressing at the Final Assembly Stage 76
  5.6 Chapter Conclusions 77
Chapter VI: Experimental Demonstration of ISA Concept 79
  6.1 Motivation 80
  6.2 Design of In-Space Assembly Facility 80
    6.2.1 Lab-scale Reflector Prototype 80
    6.2.2 Truss Builder Prototype 82
  6.3 Design Considerations 84
    6.3.1 Angle Stops and Assembly Plate Orientation 84
    6.3.2 Prestressing Method 86
  6.4 Chapter Conclusions 88
Chapter VII: Summary and Perspectives 90
  7.1 Summary 90
  7.2 Future work 92
  7.3 Perspectives 95
An Illustration of ISA Reflectors: Can E.T. "phone home" after all? 96
Bibliography 97
Appendix A: Homogenized stiffness matrix of parallel tessellation 104
Appendix B: Modification of cable stiffness in ABAQUS/CAE 105

LIST OF ILLUSTRATIONS

Number *Page*

1.1 State-of-the-art deployable structures: (a) JWST (NASA, 2016) and (b) AstroMesh deployable mesh reflector (Northrop Grumman, 1999) 2

1.2 Lightweight trusses as support structures: (a) erectable 4-meter tetrahedral truss [17] and (b) JWST support structure (NASA, 2015) . . . 3

1.3 Advancements in robotic assembly: (a) SpiderFab robot constructing a support structure for functional elements [9], Robot-Assembled Modular Space Telescope (RAMST) architecture [29]: dexterous hexbot (b) deploying and assembling truss and (c) traversing and assembling mirror module and BILL-E: robotic platform [34]: identical bipedal robots (d) using the truss as support for traversing, (e) placing and (f) moving identical truss modules. 5

1.4 Faceted reflective surface: (a) tension truss concept and (b) structural architecture of faceted deployable mesh reflector, based on [40]. . . . 7

2.1 Generalized design terminology: structural architecture of faceted deployable mesh reflector. 12

2.2 Geometry of paraboloidal reflector. 14

2.3 Faceting of paraboloidal surface: a) variation of facet size with diameter and b) schematic layout of net. 15

2.4 Three different net configurations with a) non-triangular facets, b) cross wires, and c) complete triangular tessellation. 16

2.5 Pin-jointed bar model of front net for $n = 3, n_t = 2, n_c = 2$. 16

2.6 Comparison of cable prestress distributions for $D = 200$ m, $F/D = 1.0$ corresponding to (a) 2 distinct tension tie forces, and (b) *(n + 1)* rings of tension tie forces. 18

2.7 Definition of *rings* in inner net. 19

2.8 Cable net configuration for $D = 100$ m, $n_t = 13, n_c = 3$: a) original configuration, b) mapped configuration 1, and c) mapped configuration 2. 21

2.9 Perimeter truss: a) fully deployed and stowed configurations, and b) relative position of members in stowed configuration. 24

2.10 CAD images of a) Type-1 joint with 5 struts, b) Type-1 joint strut sleeves, c) Type-2 joint with 3 struts, and d) Type-2 joint strut sleeves. 24

2.11 Areal density of reflector components ($F/D = 1.0$): a) non-optimal prestress design, and b) optimal prestress design. 26

2.12 Scaling of deployable reflectors for $F/D = 1.0$: a) total mass, b) stowed diameter, and c) stowed height. 27

2.13 Process of establishing a scaling law for the total mass. 28

2.14 Scaling of deployable reflectors for $F/D = 0.5$ and 0.7: a) total mass, b) stowed diameter, and c) stowed height. 29

2.15 Batten-supported boundary condition: a) prime batten, and b) boundary conditions in finite element model. 32

2.16 Natural frequencies and mode shapes for $F/D = 1.0$: a) frequency trends, b) first two mode shapes for prime-batten support condition, and c) first mode shape for free-free condition. 33

2.17 Natural frequency trends: a) $F/D = 0.5$, and b) $F/D = 0.7$. 34

2.18 Semi-analytical modeling scheme. 35

2.19 Semi-analytical model to estimate lateral mode: a) 1-DoF model, and b) homogenization of the net. 36

2.20 Natural frequency corresponding to lateral mode. 37

2.21 Semi-analytical model for free-free saddle mode: homogenization of a) net, and b) perimeter truss. 38

2.22 Natural frequency of free-free saddle mode: a) frequency comparison, and b) mode shape comparison. 39

3.1 Coiled strut volume estimation: a) core mandrel, b) cross section of the strut, c) flattened strut, and d) strut spool. 44

3.2 Scaling of ISA vs. deployable reflectors for $F/D = 1.0$: a) total mass, b) stowed diameter, and c) stowed height. 44

3.3 ISA concepts: (a) linear ISA trusses [9], and (b) proposed two-dimensional ISA for ring-like structures with a cable interior. 45

3.4 Schematic drawing of in-space polygonal ring assembly with cable interior: (a) truss assembly, and (b) cable net deployment. 46

3.5 Two-dimensional view of truss assembly process: first, second, third, and final bay assembly. 48

4.1 Simulation approach: perimeter ring and a single cable net. 53

4.2 Finite element model definition for a) an example polygonal ring geometry, and b) corresponding initial configuration where rods and cables are modeled with their final connectivity. 54

4.3 Simplification of cable net: (a) six-sided structure, and twelve-sided structure: (b) simplification-1, and (c) simplification-2. 55

4.4 Specified nonlinear penalty function for cable stiffness in the finite element model. 56

4.5 Framework of simulation steps. 57

4.6 Boundary conditions when a) pushing-out bays B_1 and B_2, b) activating cables connected to N_3, c) pushing out bay B_3, and d) activating cables connected to N_4. 58

4.7 Geometry of six-sided structure. 59

4.8 Angle stops: a) geometry of the structure, b) cables transitioning from slack to taut during bay push out, and c) definition of angle stop. 60

4.9 Two assembly plate orientations: a) perpendicular to the truss builder face: $\theta = 90°$, and b) tilted at angle $\theta < 90°$. 61

4.10 Cable extension results for the six-sided structure; $\theta = 90°$. 63

4.11 Cable extension results for the six-sided structure; $\theta = 60°$. 65

4.12 Intermediate polygonal shapes: (a) $\theta = 90°$, (b) $\theta = 80°$, and (c) $\theta = 60°$. 66

5.1 Geometry of twelve-sided reflector. 67

5.2 Relationship between critical assembly plate orientation, θ_{cr} and interior angle of perimeter truss. 68

5.3 Effect of assembly plate orientation: (a) $\theta = 90°$, (b) $\theta = 60°$, and (c) $\theta = 30°$. 69

5.4 Two-dimensional view of the modified prestressing method: moving truss support, i^{th} bay assembly and prestressing the structure. 71

5.5 Effect of the prestressing method: $\theta = 60°$, (a) moving last bay: S_1 is fixed (b) moving truss support: S_1 is moved by 0.1 m at the start and reset at the end of assembly. 72

5.6 Two configurations of the cable net: (a) orientation 1 (b) orientation 2. 73

5.7 Effect of cable net orientation relative to the truss support: prestressing by moving last bay and at $\theta = 60°$, (a) orientation 1 (b) orientation 2. 73

5.8 Effect of cable net orientation relative to the truss support: prestressing by moving truss support and at $\theta = 60°$, (a) orientation 1 (b) orientation 2. 74
5.9 'Jamming' condition for $\theta = 60°$, orientation 2 and prestressing by moving last bay: (a) 'jammed' configuration, and (b) resolved configuration. 75
5.10 Cable extension results for the twelve-sided reflector: $\theta = 60°$, orientation 1 and prestressing by moving last bay, (a) original cable stiffness definition, and (b) modified cable stiffness definition to reflect prestress. 76
6.1 Lab-scale demonstration: a) target reflector, and b) dimensions of struts. 81
6.2 Reflector prototype, $D = 1.4$ m: a) CAD drawing of the joint and joint-strut attachment, b) prototypes of the joint, strut, and a single bay, and prototype of cable net with c) a push-latch device installed at the outer node of cable net and attached to the truss, and d) a tension tie. 82
6.3 Truss builder prototype: a) schematic drawing of truss builder and components, and prototypes of: b) truss builder and c) manipulator. . 83
6.4 Reflector assembly demonstration for $\theta = 90°$: a) initial state, b) $i = 3$, c) $i = 5$, d) $i = 10$ with kink formation, and e) $i = 12$: completed reflector. 85
6.5 Comparison of experimental and simulation results for $\theta = 60°$: a) $i = 9$, b) $i = 11$, and c) $i = 12$: completed reflector. 86
6.6 Relationship between θ and working space for the robotic manipulator. 86
6.7 Reflector prototype assembled at $\theta = 72°$, prestressed by moving the last bay: a) collinear truss nodes, and b) undesirable stretching of cables. 87
6.8 Assembly demonstration for $\theta = 72°$, prestressed by moving the truss support: a) $i = 3$, b) truss support S_1 moved, c) $i = 7$, d) $i = 10$, e) $i = 12$: prior to repositioning S_1, and f) $i = 12$: completed reflector, overlaid with the corresponding simulation result. 88

7.1 Perforated Kapton films, 25.4 μm thick, with a 100 nm aluminized coating on one side for reflectivity: a) a single facet of cable net, with a magnified view of the perforation, patterned using a CO_2 laser, and b) achievable reduction of mass with lowered biaxial prestress, σ for $F/D = 1.0$. 93
7.2 Potential enhancements to improve packaging efficiency: (a) deployable coilable Omega boom [73], and (b) additive manufacturing of components in space [74]. 94

LIST OF TABLES

Number *Page*

2.1 Comparison of Objective Functions for $D = 200$ m, $F/D = 1.0$ . . . 20
2.2 Comparison of cable net configurations for $D = 100, 200$ m, $F/D = 1.0$ 21
2.3 Prestress range (Nets: tension; Truss: compression), for $F/D = 1.0$. 22
2.4 Size of perimeter truss members, for $F/D = 1.0$ 23
2.5 Joint masses for $F/D = 1.0$ 25
2.6 Joint masses for $F/D = 0.5, 0.7$ 29
2.7 Natural frequency of lateral mode (high-fidelity model vs. semi-analytical model) 37
2.8 Natural frequency of saddle mode (high-fidelity model vs. semi-analytical model) 39
4.1 Sensitivity to assembly plate orientation and damping coefficient . . . 62
B.1 Material definition for a single cable 105
B.2 Material definition for cable i in a multi-cable system 105

NOMENCLATURE

Space Legos. Modular components engineered for assembling structures in space.

Stationary Robot. A robot that remains fixed in position relative to the spacecraft and does not traverse across or along the structure being assembled.