

***Fundamentals of Airbreathing Rocket Combined Cycle (ARCC) Engine  
&  
Design of the ARCC Engine Powered Single-Stage-To-Orbit Vehicle***

***-Beyond the Atmosphere-***

**Tatsuo Yamanaka & Masataka Maita**

**Preface**

**Contents**

- 1 INTRODUCTION**
- 2 AIRBREATHING ROCKET COMBINING CYCLE ENGINE**
  - 2.1 Introductory Remarks**
  - 2.2 Engine Thrust**
  - 2.3 ARCC Engine Geometry and Its Special Features**
  - 2.4 Comparison with the Conventional Airbreathing Engines**
    - 2.4.1 The Governing Fluid Dynamic and Thermodynamic Equations**
    - 2.4.2 ARCC Engine Performance Measures**
    - 2.4.3 Comparison with the Turbojet Engine**
    - 2.4.4 Comparison with the Ramjet Engine**
    - 2.4.5 Comparison with the Scramjet Engine**
    - 2.4.6 Flight Speed Limits of the ARCC Engine**
  - 2.5 Integration of Engine and Vehicle**
  - 2.6 Mixing of Rocket Exhaust Gas with Incoming Air Flow**
  - 2.7 LO<sub>2</sub>/LH<sub>2</sub> Rocket Engine and Air/Hydrogen Combustion**
    - 2.7.1 Thermodynamic Equilibrium of Ideal Gas Mixtures**
    - 2.7.2 Adiabatic Flame Temperature**
    - 2.7.3 Combustion of the LO<sub>2</sub>/LH<sub>2</sub> Rocket Engine**
    - 2.7.4 Fuel/Air Combustion**
  - 2.8 Boundary Layer and Transpiration Cooling**
    - 2.8.1 Turbulent Boundary Layer**
    - 2.8.2 Transpiration Cooling**
    - 2.8.3 Averaging of the Boundary Layer Effect**
  - 2.9 Performance of an ARCC Engine by Numerical Calculations**
- 3 ARCC ENGINE POWERED SINGLE STAGE TO ORBIT SPACE TRANSPORTATION VEHICLE**
  - 3.1 Introduction to Single Stage To Orbit Space Transportation Vehicle Design**
  - 3.2 Planform and Airfoil Selection**
  - 3.3 Wings**
  - 3.4 Takeoff and Landing**
  - 3.5 Numerical Vehicle**
  - 3.6 Mass Distribution Properties**
  - 3.7 Aerodynamics of the Propulsive Lifting Body**
    - 3.7.1 Two-dimensional flows with small perturbations**
    - 3.7.2 Subsonic flow**
    - 3.7.3 Transonic flow**
    - 3.7.4 Supersonic flow**
    - 3.7.5 Hypersonic flow**

- 3.8 External Nozzle Expansion Gas-dynamics and Interaction with Free Air-stream**
  - 3.8.1 Free Jet-Boundary**
  - 3.8.2 Interference of Nozzle Exhaust Gas Flow with Atmospheric Air Flow**
  - 3.8.3 Lift and Drag Due to Nozzle Exhaust Gas Flow**
  - 3.8.4 Numerical Examples**
- 4 FLIGHT AND ATTITUDE CONTROL DYNAMICS**
  - 4.1 Introductory Remarks**
  - 4.2 Flight Trajectory Analysis**
  - 4.3 Attitude Control Dynamics**
  - 4.4 Dynamics of Takeoff**
- 5 FLIGHT PERFORMANCE OF AN ARCC ENGINE POWERED SSTO VEHICLE**
  - 5.1 Introduction**
  - 5.2 Design Process of a Numerical Vehicle by Means of Flight Simulation**
  - 5.3 An Example of the Numerical Vehicle**
  - 5.4 Weight Estimation**
  - 5.5 Flight Analysis**
    - 5.5.1 Aerodynamics**
    - 5.5.2 Flight Dynamics**
    - 5.5.3 Guidance and Control**
  - 5.6 Numerical Results of a Flight Simulation**

## PREFACE

This book was written for the commemoration of the authors' research works toward spaceplane, Authors have been conducting Japan's Spaceplane program at National Aerospace Laboratory since early 1990's, with the vehicle concepts focused on the airplane-like space vehicle powered by airbreathing rocket combined cycle (ARCC) engines.

Single-Stage-To-Orbit (SSTO) vehicle was the leading reference concept.

For SSTO vehicle to be feasible, development of the high performance propulsion system is of key issues. With these objectives in minds, we had proposed the novel concept on the propulsion system ,continuous from low flight speed to the high flight speed regime based on the non-Brayton cycle. As compared to the Rocket-Based Combined Cycle (RBCC) propulsion system, ARCC's unique features are on minimizing the variable geometries as possible.

*Prof.Dr. Tatsuo Yamanaka, National Yokohama University (retired)*

*Prof.Dr.Masataka Maita, Japan Aerospace Exploration Agency JAXA*