Investigation of novel propulsion systems – the exoskeletal engine concept. Part I

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Abstract: *The exoskeletal engine represents a relatively new concept in the world of propulsion systems. It is a drum-rotor engine concept in which conventionally heavy shafts and discs are eliminated and replaced by rotating casings that support the blades in span wise compression. Thus the rotating blades are in compression rather than in tension. The resulting open channel at the engine centreline has an immense potential for the jet noise reduction and can also accommodate an inner combined-cycle thruster such as a ramjet. This is the first part of an article constituted out of two parts.*

Key Words: exoskeletal engine, novel propulsion systems, high temperature composite materials, hybrid materials/structures.

1. INTRODUCTION

In order to improve the design of conventional turbine and compressor, it is hypothesized that the use of ceramic materials would provide a greater efficiency due to the loss in engine weight and higher functioning temperatures. Some problems involved in the use of ceramic materials are the lower tensile strength, durability and damage tolerance, when compared with the materials used in/with conventional engines (refractory metals, nickel-based alloys, such as titanium, Hastelloy and Waspaloy). Ceramic materials are known to be more resistant in compressive loading cases where the brittle fracture is minimized. A novel turbine design approach based on this characteristic of the composite ceramic materials is the exoscheletal engine (Exo-skeletal engine – novel engine concept, Christos C. Chamis and Isaiah M. Blankson, National Aeronautics and Space Administration, Glenn Research Center, Cleveland, OH, August 1997). The Exo-skeletal engine concept subjects all rotating parts to compression, permitting the use of notch-sensitive materials such as homogeneous ceramics. It reduces the rolling-bearing stress by permitting multiple rows of bearings, thereby minimizing or even eliminating lubrication and cooling. This concept allows a progressive thrust growth capacity as well as reduces the engine size. It can be applied to subsonic, supersonic and hypersonic engines. Some benefits, both quantitative and qualitative, include: elimination of bore stresses, increased tip speed, increased bearing life, increased flutter boundaries, reduced airfoil thickness, elimination of containment requirements, increased blade high-cycle fatigue life, reduced parts counts, decreased sealing and cooling requirements and reduced blade-tip and case wear[4,5].

A cross-sectional diagram of an exoskeletal single spool engine concept is shown in Fig.1 below. Some of the characteristic differences as compared to the conventional engine technology are as follows:

(a) Compressor and turbine blades are mounted to/in the inside of a drum rotor. Stators and combustors are mounted to a stationary hub. Blades are in compression instead of tension because of the rotational inertia. Torque is transferred from turbines to compressors through the rotating drums.
(b) The drum rotor is supported by the bearings between the outside of the rotor and an outer shell. In a multispool engine, the high-pressure drum rotor bearings may ride directly on the low-pressure spool drum rotor. In a partially exoskeletal engine, thrust and other forces are transferred through bearings between the drum rotors and shells or hubs.
(c) For engines of sufficient size, a central core space (inside the stator rings) may be open.

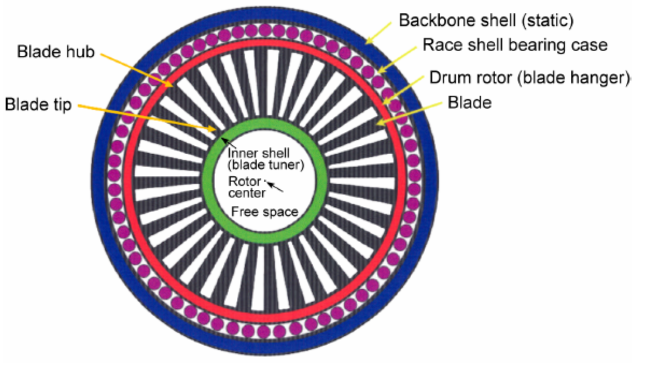

Figure 1. – Exoskeletal engine concept projected view of the exoskeletal engine composite rotor.

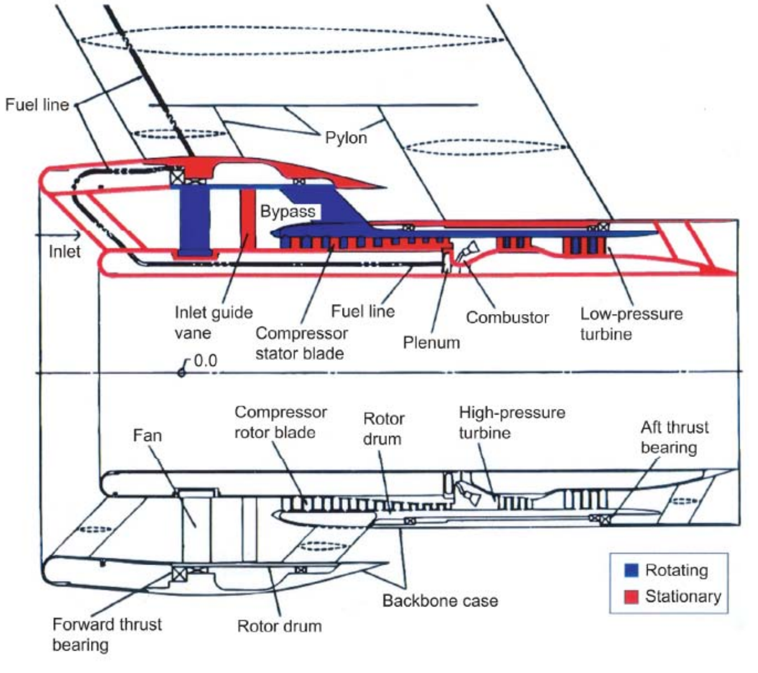

Figure 2. – Single-spool exoskeletal engine concept.

2. RELATED PRIOR PROJECTS

General Electric Unducted fan.[2,3] – The General Electric unducted fan (UDF), developed as part of NASA's advanced turboprop program in the 1980s, represents a successful, if not entirely similar, flight-proven predecessor to the exoskeletal engine concept shown as shown in Fig.3. The UDF engine consisted of a standard high-pressure engine spool to which a low pressure turbine (LPT) was added to directly drive a set of counter rotating highly swept propellers, also called unducted fan blades. The aft row of fan blades was driven by a conventional axial turbine, but the forward row of the fan blades was driven by several rows of turbine blades mounted at their outer edge to a rotating drum. On the UDF, this drum was connected to and supported by a more conventional disk. Because the UDF low-pressure turbine drove a set of high-speed propellers (or a low-speed unducted fan), the wheel speeds were low compared with turbofan engines, thus centrifugal forces were not a factor in blade or drum design. In this respect, the UDF represents a significantly different set of design objectives and experience from those that would be relevant to an exoskeletal engine concept. However, the UDF represents the successful implementation in flight of some elements of an exoskeletal engine architecture.

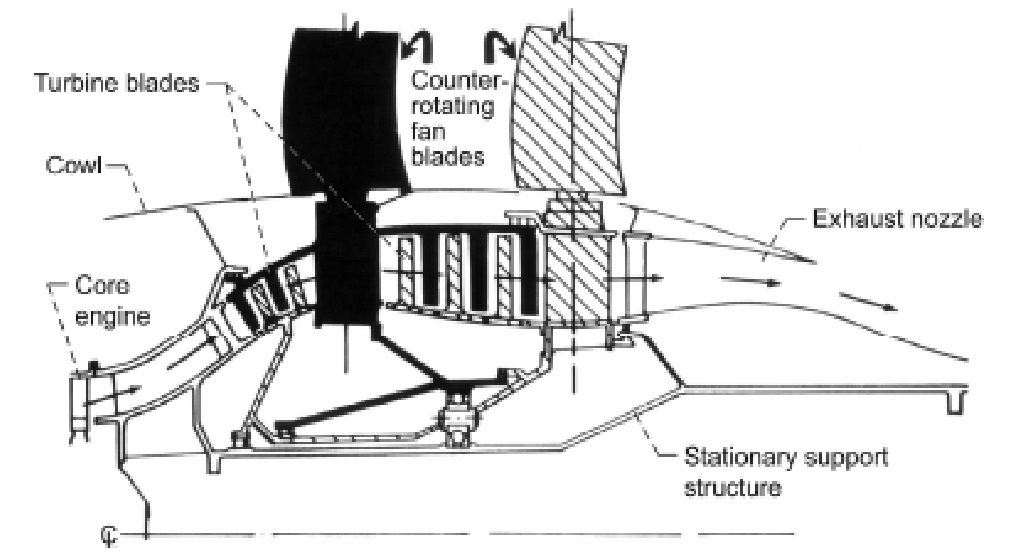

Figure 3. – General Electric unducted fan propulsor concept

Modern technologies Corporation exoskeletal engine concept studies. [3] – NASA sponsored studies of the exoskeletal engine concept were conducted by Modern Technologies Corporation between 1999 and 2001. These studies examined exoskeletal design concepts for 2000-, 5000-, and 25 000-lb thrust-class engines. The Preliminary design concepts consisted of cycle definition and stage number and size definitions (no structural analyses were performed). The studies pointed out the critical need for the exoskeletal engine preliminary design guidelines and structural constraints on the design because of the departure from the conventional engine design practices.

Honeywell International Incorporated, exoskeletal engine study. [1, 3] – In early 2000, Honeywell International Inc. developed an exoskeletal engine concept based on an existing engine. Honeywell selected the AS900 engine (approx. 6500-lb thrust at sea level static conditions) as a basis for comparison. A single-spool concept was assembled but was rejected because of performance, operability, and engine-starting limitations as compared with two-spool configuration. A two-spool concept engine was assembled. A layout of this concept was created, and an engine cycle simulation was assembled sufficient to calculate the performance of engine components. Hoop stresses in the drum rotors were calculated and were used to identify material options and weights. High-pressure spool (HPS) rotation speeds necessary to produce performance similar to the AS900 required bearings operating at approximately 9 million mm-rpm, beyond the state of the art for bearings. The performance of a lower speed high-pressure spool was calculated for a rotation speed within the state-of-the-art bearing capabilities of 6 million mm-rpm. The Engine weights were calculated for rolling-element and magnetic bearing options, and weights and performance were compared with the AS900 engine. The Major conclusions of this effort were:

(1) An exoskeletal engine concept that delivers similar performance to an existing conventional engine is feasible but would have a radius approximately 30 percent smaller and would be approximately 50 percent longer.

(2) Exoskeletal rotating machinery is lighter (in concept) than that for the conventional engines.

(3) Bearing system weight for an exoskeletal engine increases the total weight of the engine to 20 to 25 percent greater than that of a conventional engine.

It should be noted that the Honeywell AS900 engine has a centrifugal high-pressure compressor (HPC). Centrifugal compressors generally add weight and diameter but decrease the length of gas turbine engines. This creates some ambiguity about the directness of the comparison between the AS900 engine and a completely axial exoskeletal engine. However, the Honeywell study represented the first known assessment of the exoskeletal concept applied to an engine as a system. The findings of the Honeywell study indicated the importance of the engine systems approach in any subsequent investigations, as well as the predominance of engine structures, materials, and bearings in the application of the exoskeletal concept.

3. THE EXOSKELETAL ENGINE

The exoskeletal engine concept eliminates the central heavy discs and shaft that are in conventional gas turbine engines. Instead, it utilizes a drum rotor with the blades hanging inward from the outside [1, 5]. The concept has three main features:

(1) a drum-rotor configuration that subjects all the rotating parts to compressive stress fields;

(2) an all composite engine for light weight and for higher ratios of strength and stiffness to density, and

(3) unitized components and subassemblies to reduce the part count.

The drum-rotor configuration consists of four concentric composite shells: (1) an inner composite shell, which is static and provides for flow path through the centre cavity; (2) a stator shell, which is static and supports the guide vanes, (3) a drum-rotor shell, which rotates and supports all blades, and (4) an outer of backbone shell, which supports the bearings and is designed with acceptable hoop stresses to constrain the drum-rotor shell to specified or no radial growth. The unitized component subassemblies include the inlet, the fan stage, the low-pressure compressor stages, the high-pressure compressor stages, the high-pressure turbine stages, the low-pressure turbine stages, and the exhaust. A longitudinal section of the exoskeletal engine assembly is shown in Figure 5. Longitudinal sections of the inner shell, the stator shell, the drum-rotor shell and of the exterior backbone shell are shown in Figure 6, 7, 8 and 9 respectivelly.

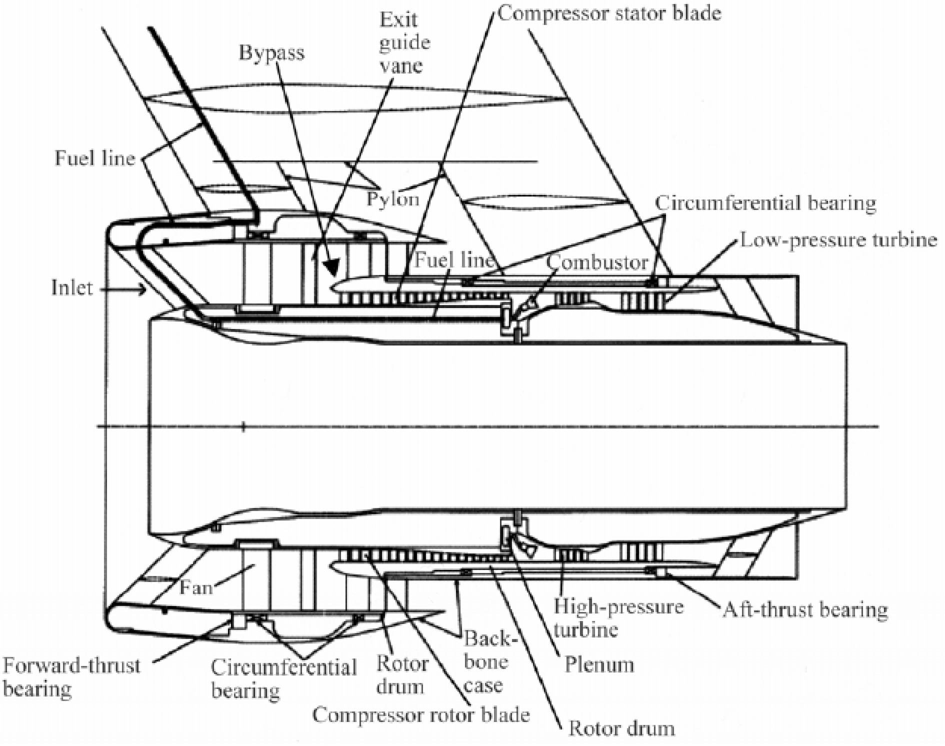

Figure 5. – Longitudinal section of an assembled exoskeletal engine

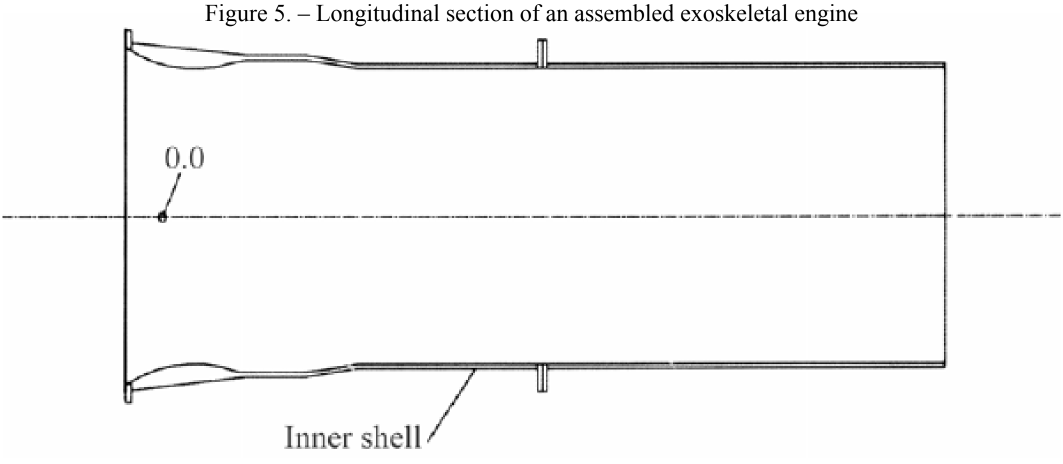

Figure 6. – Longitudinal section of the exoskeletal engine inner shell

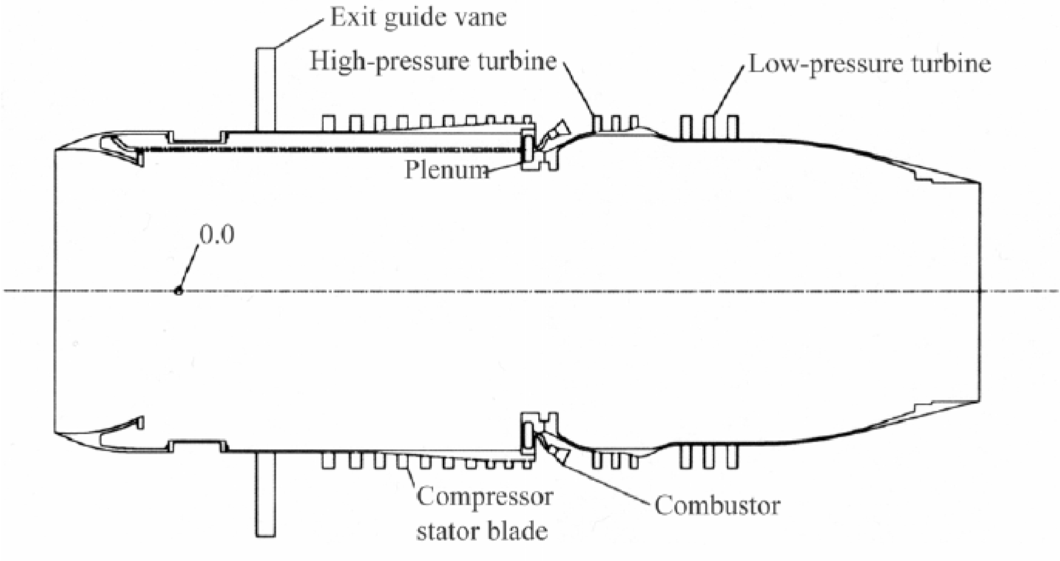

Figure 7. – Longitudinal section of the exoskeletal engine stator shell

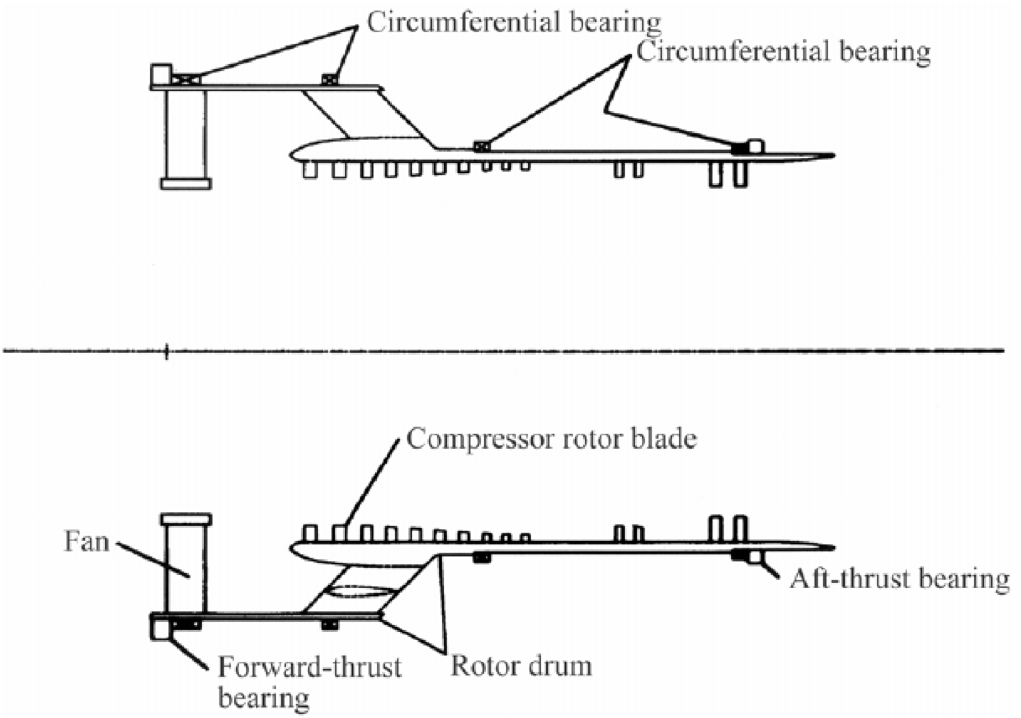

Figure 8. – Longitudinal section of the exoskeletal engine rotor (drum-rotor) shell

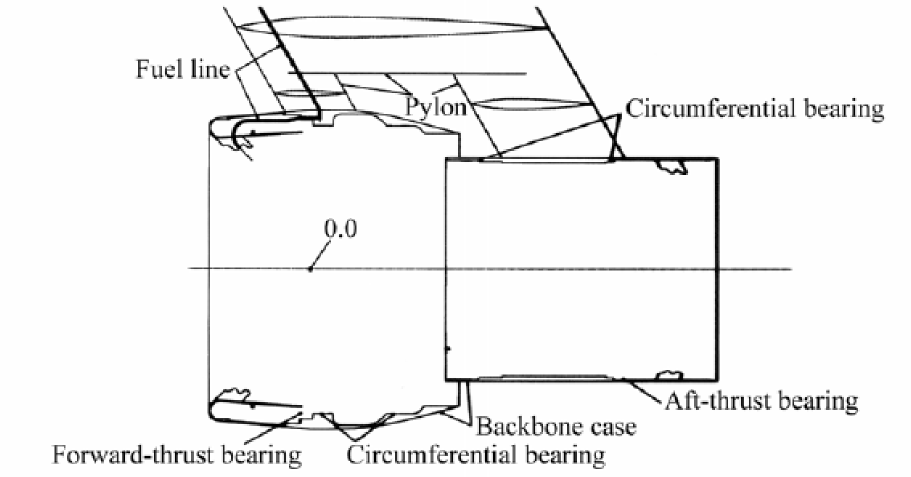

Figure 9. – Longitudinal section of the exoskeletal engine exterior (backbone) shell

A low pressure turbine is included in Figure 5 in case a two spool arrangement is needed, which may be the case in order to accommodate improved efficiency operations at off-design points. It is also noted that the combustor is assumed to be the same as that of a conventional high-bypass-ratio engine. Some high-temperature composites may be used in the combustor as the detail design matures. It is also envisioned that a gearbox may be needed, which will become evident during detail design of the exoskeletal engine. It is noted that at this point, the fabrication process of such an engine is by far the major challenge. A strong point in this affirmation is the bearing subsystem design. The alternatives taken into discussion will be presented in the second part of this article, together with the conclusions.

REFRENCES

[1] Ian Halliwell, , Exoskeletal Engine Concept: Feasibility Studies for Medium and Small Thrust Engines. NASA/CR – 2001-211322, 2002. http://gltrs.grc.nasa.gov/reports/2001/CR-2001-211322.pdf

Bill Gunston, ed.:Jane's Aero-Engines. Issue 14, Jane's Information Group Limited, Coulsdon, Surrey, 2003.

[2] ***Maintaining U.S. Leadership in Aeronautics: Breakthrough Technologies to Meet Future Air and Space Transportation Needs and Goals. Contract No. NASW-4938, National Academy Press, Washington, DC, 1998.

[3] Latife Kuguoglu; Galib Abumeri and Chamis Christos: Structural Evaluation of Exo-Skeletal Engine Fan Blades. AIAA 2003-1861,2003.

[4] Joseph M. Roche, Donald T. Palac, James E. Hunter, David E. Myers, and Christopher A. Snyder: Investigation of Exoskeletal Engine Propulsion System Concept, NASA/TM – 2005-213369

[5] Arun K. Sehra and Jaiwon Shin: Revolutionary Propulsion Systems for the 21th Century, NASA/TM – 2003 – 212615

[6] Roy Sullivan:Thermal Analysis of a Carbon-Carbon Bearing Design for Exoskeletal Engine Bearings. NASA/TM – 2001-210946, 2001.

[8] Abumeri, Galib H.; Kuguoglu, Latife H.; and Chamis, Christos C.: Composite Fan Blade Design for Advanced Engine Concepts. NASA/TM 2004-212943, 2004.

[9] ***Metallic Materials and Elements for Aerospace Vehicle Structures. MIL−HDBK−5F, 1990.

[10] Chamis et al., U.S. Patent no.US6393831, May 28, 2002

[11] Benzakein, M.J., The Future of the Jet Engine, GE Presentation, Cincinnati, OH, May 28 2008

[12] Abumeri, Galib H.,Chamis C.Christos, Probabilistic Evaluation of Advanced Ceramic Matrix Composite Structures, NASA/TM-2003-212515, Glenn Research Laboratory, Ohio, 2003

[13] Sehra, K. Arun and Shin Jaiwon, Revolutionary Propulsion Systems for 21st Century, NASA/TM – 2003-212615, Glenn Research Laboratory, Ohio, Cleveland, 2003