station-keeping and collocation of geostationary satellites and will prove beneficial to the modeller and operator/analyst alike in providing background rationale for particular operational strategies.

The chapter on the strategies and long-term stability of end of life disposal orbits is very helpful in explaining the need for, and practical implementation of, measures to limit the proliferation of space debris by removing satellites from crowded orbits once a mission is complete. This topic is further elaborated with a dedicated chapter on space debris, explaining the background history and predicted future evolution of the space object population, outlining some models that are available to the practitioner and relevant disposal strategies, in addition to underlining the need for space surveillance and tracking.

Finally, the appendices are a very useful source of orbital theory ranging from third body gravitational perturbation through solar radiation pressure impact and simplified solutions to both conservative and non-conservative force influence on trajectories.

This book is recommended to both undergraduates and postgraduate students and is a very valuable reference for mission designers and those involved in the day-to-day operations of satellites and is an excellent primer for any aspiring astrodynamicists.

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Aerospace Materials and Material Technologies Vol 2: Aerospace Material Technologies

Edited by N. E. Prasad and R. J. H. Wanhill

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Volume 1, subtitled 'Aerospace Material, was reviewed in *The Aeronautical Journal* May 2018. Volume 2, subtitled 'Aerospace Materials Teachnologies' is presented in four Parts: Part 1 – Processing Technologies; Part 2 – Characterisation and Testing; Part 3 – Structural Design; Part 4 – Special Technologies, is the subject of this review.

'Processing of Aerospace Metals and Alloys: Part 1 – Special Melting Technologies' – Chapter 1 – starts at the ingot stage where Electric Magnetic Vacuum Induction Melting (VIM and Post VIM) are processes recommended as the surest way of transforming raw metal bulk into near flawless high grade material stock (see Chapter 2).

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The authors claim that (VIM) followed by Post VIM ensures melt cleanliness and precise chemical control. Solidification phenomena, remelt refinements and possible defects are issues considered. Two case studies relating to investment casting of nickel based superalloy gas turbine blades and the control melt processing of Inconel 718 are also included.

'Processing of Aerospace Metals and Alloys: Part 2 – Secondary Processes, – Chapter 2 – explains how large ingots, known as blooms, are reshaped and structurally refined by a series of forceful forging actions (known as upsetting), which cause significant plastic deformation and induce a marked change in shape. Figure 2.1 shows 11 different stress states which may be imposed during traditional forging, rolling and/or extrusion processes: Equal channel extrusion (involving shear deformation without change in shape); the LENS process (used for rapid prototyping); high pressure torsion; cryomilling (ball milling of element or alloy powders) and vacuum plasma spray forming and electrodeposition, number among less well-known processes discussed.

'Superplastic Forming of Aerospace Materials' – Chapter 3 – contains numerous examples of how superplasticity involving elongations of up to 200% is currently used to fashion highly efficient, lightweight structural components of various 3D shapes and sizes. Bulge forming; pressure forming; thermoforming; blow forming; deep drawing; power metallurgy; diffusion bonding and roll forming are specific methods discussed.

'Welding Technologies in Aerospace Applications' – Chapter 4 – promotes various high-tech welding processes, used and approved for joining high-strength aluminium, titanium, steels and nickel-based alloys. Welding methods discussed include gas tungsten arc; plasma arc; gas metal arc and friction stir techniques. Brazing is briefly mentioned in the context of gas turbine blade and vane repair. The difficulty of welding dissimilar metals is explained and how to weld metal matrix composites and intermetallcs discussed in Section 4.2.5–4.2.7. Ceramic to metal joints are also considered.

'Nanomanufacturing for Aerospace Applications' – Chapter 5 – is defined as a process of building 1, 2 and 3D structures from particles in the 1–100 nm range, the aim being an improvement of material properties. The so-called bottom up and top down options are discussed. Chemical vapour disposition, atomic layer disposition, crystal growth and self-assembly are processes characteristic of the 'bottom up approach' – mechanical milling, thermal/chemical methods being representative of the top down alternative approach. Thermal insulating aerogels, enhanced energy storage capacity and the use of graphene are cited as current uses. Nanosensors are not considered.

'Microstructure: An Introduction' – Chapter 6 – presents a brief but informative introduction to microscopic instruments and examination techniques. The fundamental importance of metallic micro structure is stressed and its study promoted by descriptions of how the various systems work:

Including optical microscopy, scanning electron microscopy (offering magnifications from 10,000 to 50,000 times), high temperature microscopy, field ion microscopy and atomic probe microscopy.

'Texture Effects in Important Aerospace Materials' – Chapter 7 – explains that

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crystallographic textures produced by casting/rolling/forging/extruding/drawing are inevitably different. One observation is that wrought processes often produce anisotropic mechanical properties, which may render a preferred material unsuitable for a particular application. The so-called solidification textures, formed when casting turbine blades and vanes in superalloys or aluminide materials, may also result in rejection of the product. The text also explains how ultrasonic and X-ray diffraction methods are used to assess textural effects and implications.

'Physical Property Significances for Aerospace Structural Materials' – Chapter 8 – includes several full page tabulations which show how a material's physical properties (thermal expansion, density, etc.) may affect self-weight and structural efficiency. Suffice to say that Figure 8.1, based on an ASTM technical publication STP 370 dated 1960 (repeated from Vol. 1, p. 57) shows four linear through zero plots for four property improvements vs weight saving predictions: surely a simplification over such a wide range, other sections on alloy classes and alloy selection being more relevant and reliable. Section 8.3.3 headed Inadvisable Alloy Selection provides an assessment of the demise of Concorde, TSR-2, SR-71 and F-111, in which the authors acknowledge the benefit of hindsight. The chapter concludes with a brief account of thermal barrier coatings.

'Structural Alloy Testing: Part 1 – Ambient Temperature Properties' – Chapter 9 – explains how material properties at ambient temperature are obtained by testing preprepared samples in the laboratory. Noteworthy topics include the following: fatigue crack growth (at constant and variable amplitudes) and plane stress and plane strain variants of fracture toughness, illustrated graphically but without equations. The section on corrosion and stress corrosion cracking is likewise wholly descriptive, albeit numerous guidelines are given and 50 references provided which give credence and substance to the text.

In 'Structural Alloy Testing: Part 2 – Creep Deformation and Other High-Temperature Properties' – Chapter 10 – Section 10.1 introduces creep behaviour in primary, secondary and tertiary phases, the so-called steady state second phase being defined by the standard power-law equation. Section 10.3 explains how creep fractures are characterised by intergranular failures, the exact nature of which may vary, depending on the interaction of numerous factors: temperature levels, strain rate, grain boundary sliding, etc. See Figure 10.6 for a schematic of a typical creep testing rig. Classical methods of data collection and more recent procedures are also explained. Sections on Dwell cracking (when hold times are applied) and creep crack growth in general conclude the chapter.

'Non-destructive Testing and Damage Detection' – Chapter 11 – reports that there are more than 50 NDT techniques in widespread use today. Traditional and newer fast track automated, cost effective, in situ techniques are allocated full section coverage. These range from: visual surface inspection; optical methods; liquid penetration (of cracks); magnetic particle technique and eddy current; volumetric acoustic, ultrasonic, X-ray and neutron radiographic procedures.

'Design of Aircraft Structures: an Overview' – Chapter 12 – summarises numerous

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basic principles which relate to the design of stiffened (monocoque) structures, typical of aircraft wings and fuselages. Landing gear requirements and aeroelastic issues are likewise treated at a basic level.

'Aircraft Mechanical Systems' – Chapter 13–describes flight control, fuel supply circuits, environmental and life support systems at a very basic level, albeit fly-by-wire and power-by-wire, which involve electric/hydraulic actuators and digital computer control that are considered brief en-passant.

The main body of the text of 'Design and Structures of Aircraft Engines' – Chapter 14 – is devoted to conceptual, preliminary and detail design procedures, an approach to blade and disc design (see block diagram Fig 14.4) being one example. Design tools specifically mentioned include the following: the Campbell/Goodman diagrams, the Palmgren–Miner Rule and the Coffin–Manson Relationship. A brief discourse on testing and validation is also included.

'Missile Propulsion Systems' – Chapter 15 – contains many annotated schematics which illustrate component layouts and working principles. To paraphrase the authors: rocket propulsion utilises a mixture of oxidizer and fuel, in liquid or solid form, whereas ramjets and scramjets are air-breathing devices which store fuel in the vehicle but use atmospheric air to feed combustion. Hence, their use is limited in altitude, to about 20km.

'Fatigue Requirements for Aircraft Structures' – Chapter 16 – opens with a formidable 46 item list of two or three letter abbreviations, after which Section 16.1 traces the evolution of fatigue requirements which have evolved as a consequence of aircraft crashes and inflight failures. The impact of DH Comet pressure cabin disintegrations (1954), Dan Air Boeing 707 loss of horizontal stabilizer (1977), Boeing B47 loss in 1958, General Dynamics F-111 (1969) and Aeromacchi MB 326H (1990) are short accounts described as 'milestone accident' events well worth reading. Short crack analysis, stress-life, strain-life and damage tolerance approaches are considered.

'Full-Scale Fatigue Testing' – Chapter 17 – gives full credit to Wohler (a railway depot superintendent working in Prussia) who initiated the study of fatigue of axles prior to publication in 1870. The fact that service loads are of a statistical nature in practice is acknowledged by the authors but the well-known diagram showing the statistical normal distribution of load and load capacity is not made known to the reader. Nevertheless, Figures 17.1 and 17.2 present a comprehensive rendering of the Aircraft Structural Integrity Program (ASIP).

'Residual Strength Requirements for Aircraft Structures' – Chapter 18 – is a topic pre-empted by discussions in Chapter 16. The concept of limit load, ultimate load and the notion of safety factor are introduced belatedly on page 377. The text records that the fail-safe approach was used between 1956 and 1978, albeit the damage tolerance approach was introduced c1970. It is clear to the reviewer that the first half of this chapter should precede and not follow Chapter 16.

'Stress Corrosion Cracking in Aircraft Structures' – Chapter 19 – emphasises the high cost of downtime associated with the need to rectify ongoing degradation. The authors point out that even the so-called stainless steels and lightweight magnesium alloys, the latter used for helicopter gearbox

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casings, are not immune from corrosive erosion in one or other of its various forms. The bulk of the chapter is, therefore, full of advice on the selection of materials and use of preventative measures currently taken to ensure a serviceable structure is maintained throughout an aircraft's life time.

'Aero Stores (Materials) Inspection and Quality Assurance' – Chapter 20 – stresses the importance of quality control and ongoing maintenance. Section 20.7, for example, lists 64 factors (issues) that need to be addressed. Specific points about the use and maintenance of aluminium alloys, titanium alloys, superalloys and composite materials are briefly discussed.

'Fatigue Life Enhancement for Metallic Airframe Materials' – Chapter 21 – suggests nine ways in which residual stresses may be beneficially introduced. The importance of reducing geometrical stress concentrations, caused by poor design or by poor manufactured quality, is briefly referred to without off examples.

'Structure Health Monitoring' – Chapter 22– emphasises the importance of diagnostic/prognostic procedures. Health and Usage Monitoring Systems (HUMS) using electrical strain gauges and use of damage monitoring acoustic ultrasonic procedures are discussed, as also several other methods. Fibre optic, interferometric and grading sensors are described and a few practical examples given. The bibliography is extensive.

'Failure Analysis and Prevention' – Chapter 23 – provides a more or less conventional introduction to ductile, brittle and fatigue failure augmented by fractographs for the benefit of those with a microscopic eye. General topics considered include: hydrogen embrittlement, stress corrosion cracking, wear and overheating.

'Airworthiness Certification of Metallic and Non-metallic Materials' – Chapter 24 – is presented from an Indian aviation perspective, for which 76 abbreviations apply. The main objective of their endeavour is to ensure a high level of safety and reliability. Various certification flow charts, Figures 24.1 and 24.5, summarise the proceeds. 'Lightweight Ballistic Armours for Aero-Vehicle Protection' – Chapter 25 – starts on a depressing but realistic note by warning that "Ballistic armour technology will become increasingly important in coming years...." Ballistic threats and passive/reactive armour systems are discussed. The need for light weight is emphasised and the use of layered ceramic matrix composites (CMCs) proposed. A typical build consists of an outer ceramic layer to blunt and fracture the impacting projectile and other layers to slow and muffle the remnants. Transparent armour used on helicopters is also considered.

The reviewer is pleased to report that the 50 or so authors of Vol. 2 have maintained the high standard set by the 50 or so authors of Vol. 1. The editors also deserve full credit for their skill in presenting the diverse work of so many others, notwithstanding their failure to supply an index. These two volumes fulfill the aim of providing a comprehensive source of reference suitable for everyday desk top use, preferable to bulky internationally recognised standard volumes, even when these tomes are available in E-book form.

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