Whole Aircraft Design: So What …?

V 0.1 Beta

Abstract or Executive Summary

A Collection of LinkedIn Chapter Summaries

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Chapter 1: Introduction

This chapter describes the need and purpose of the book and introduces the concept of 'So What ...?.

Chapter 2: Ten Basic Rules of Whole Aircraft Design.

1. Good, robust requirements are critical
2. Think broad, rather than narrow
3. Whole aircraft design is not deterministic
4. Keep your eyes on the prize - 'so what?'
5. Use consistent analysis levels and as simple as possible to deliver a robust result
6. Always calibrate your design models with known representative aircraft
7. 'There is nothing new under the sun'
8. Take expert advice and then do what you think best (see picture)
9. Technologies rarely deliver all of their promise
10. Always consider a lower-risk option against a radical solution

These 'rules' are what I use to guide aircraft conceptual design activities rather than hard rules that must be followed.

i) **Requirements** - stretching an aircraft's requirements (e.g. design range or field performance) to satisfy a niche customer can compromise the operating economics at the market sweet spot. VC-10 with sparkling TOFL vs 707;

Laying longer runways enabled 707 access to the hot and high airports the VC-10 targeted;

ii) **Broad not narrow** - Multiple fuselage lengths and freighter or military variants all increase the potential number of airframes produced.

How can an aircraft incorporate new technology during a 50-year programme;

iii) **Not Deterministic** - The Saab 340 and Dornier Do328 are 30-40 seat aircraft designed within a decade of each other. The Saab is low-winged, the Dornier a high-wing. Gulfstream bizjets include no leading-edge slats, competing Bombardier aircraft do.

The same markets, different solutions;

iv) **'Eyes on the Prize'** - The 'prize' is a commercially successful programme that usually requires lots of airframes sold at a profit to cover the development costs. Sales success requires the customers making a profit with the aircraft.

All focus should ultimately target these objectives. Safety is a given;

v) **Consistent, simple analysis** - don't overcomplicate the task - increasing complicated methods increases the scope for screwing up or the likelihood of not understanding why a result was reached.

The lowest fidelity tool in an aircraft design suite sets the overall fidelity.

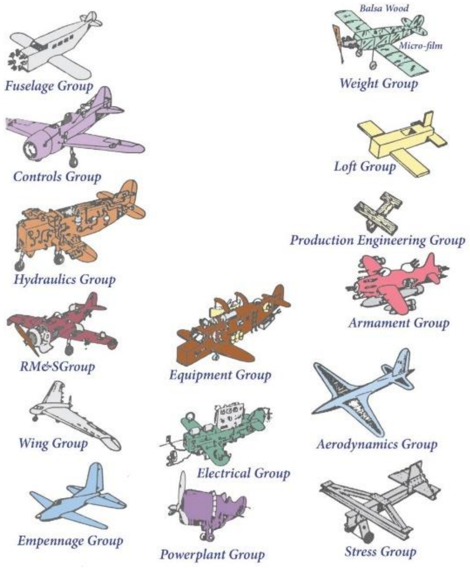
vi) **Model Calibration -** If your design system is not calibrated with a representative baseline aircraft, treat any results for a new concept with suspicion. A certificated aircraft's reported characteristics are much more reliable than a method's results.

vii) **'Nothing New Under the Sun' -** The first distributed propulsion aircraft used chains to share a single engine power input to two propellers. It occurred in 1903 in Kittyhawk, USA – the Wright Flyer. The first powered air vehicle was a steam-powered model flown in 1849 in Chard, UK. The first reported human to fly in a heavier-than-air vehicle was an unknown child in the late 1840s in Yorkshire, UK.

The first eVTOL quadcopter flew in 1918, the PKZ-1. Connected to the ground-based generator, an alternative to an artillery observation balloon.

viii) **Take expert advice and then do what you think best -** Many Subject Matter Experts try to direct whole aircraft decisions, often with a bias to their own speciality – a bit like the image in this post.

Listen carefully but decide what's the best solution for the programme (back to eyes on the prize).



ix) **Technologies rarely deliver all their promise -** Getting a novel technology or feature onto a certificated aircraft almost always falls short of the research team's promises.

Typically, certification considerations or interactions with other whole aircraft design aspects (including cost) compromise a specific technology's whole aircraft impact.

x) **Risk Management -** An industrial aircraft design must consider programme risk. Airframe companies' bet the company' on a new product. There is a long list of examples where one or two poorly executed, but hugely expensive aircraft programmes caused bankruptcy or market exit for the company concerned.

If a derivative programme delivers almost all the improvement of a clean sheet design at 20-25% of the development cost and risk, why bother with the latter? For example, the A320neo and 737Max programmes.

Chapter 3: Transport Aircraft Design – Brief History and Status

An aircraft design textbook is essentially a status report on a technology flow starting over 170 years ago and expected future developments.

This chapter attempts to place 'Whole Aircraft Design: So What?' book in that broader flow with a brief timeline from the Wright brother's first powered flight in 1903 through to the near future (with references to much better documents providing historical context). The timeline focuses on key technical, architectural and market developments rather than numbers.

The chapter also introduces the basics of Whole Aircraft Design, describing why various aircraft configurations serving different market segments tend to look the way they do.

It also addresses various niche (in 2023) aircraft classes that various airframe companies tackled historically, some successfully, others less so, e.g. STOL, VTOL (other than helicopters), supersonic, seaplanes, wing-in-ground effects, etc. Again, each includes the rationale for the typical aircraft configurations and thoughts on why they currently receive limited market interest. It also considers what market conditions might possibly revive their interest levels.

Chapter 4: Aircraft: The Basics

This large chapter forms a reference or foundation for many of the following chapters. Much is pretty standard for aircraft design textbooks, but it is critical to understand the rest of the book.

Part 1 covers the basics of the atmosphere and aircraft performance.

Part 2 address provides a similar foundation for more whole aircraft design and analysis subjects

The most noticeable new elements involve:

i) The concept of aircraft performance as energy flows (see image: climb/cruise/descent energy flows).
ii) A single chart linking weight, lift, drag and thrust using a compound chart, often seen in flight manuals.

Later chapters use these definitions to build mission performance and field performance models for whole aircraft analysis.

Part 1

THE ATMOSPHERE

We start with the fluid through which the aircraft moves and how it changes, both the International Standard Atmosphere definition and the real one.

It also discusses the various relationships connecting 'True', 'Indicated', 'Calibrated' and 'Equivalent' airspeeds and Mach number, and how to convert between and model these. It also discusses the role of each in aircraft design and performance.

AIRCRAFT DEGREES OF MOVEMENT

Roll, Yaw and pitch around each of the 3 axes, as well as movement along them.

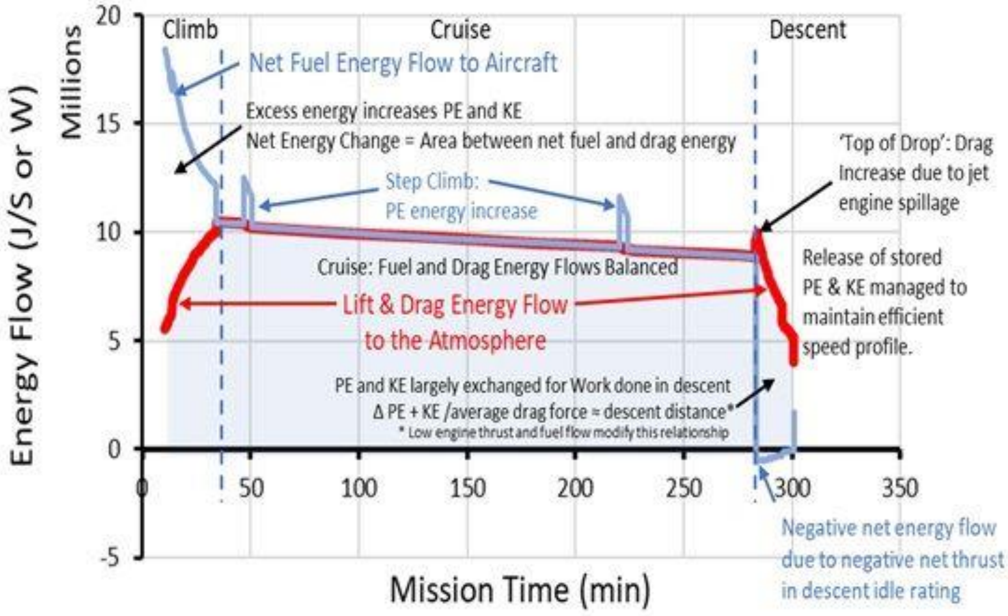
FUNDAMENTAL AIRCRAFT COMPONENTS AND TERMS

What is a wing? Obvious, but needed for completeness. Lots of geometric terminology including the various wing area definitions used by different manufacturers.

FORCES ACTING ON AN AIRCRAFT

Lift, Weight, Drag and Thrust definitions – they are in every book, but are fundamental, so must be included.

AIRCRAFT ENERGY FLOW



All aircraft performance is an energy flow as the energy conservation law states that it cannot be destroyed or created. It needs understanding.

Steady state cruise with almost constant potential and kinetic energy state (actually slightly reducing) still involves a flow of fuel energy. Where does it go?

FORCE COEFFICIENT

The standard force coefficient widely used to non-dimensionalise lift and drag forces.

AIRCRAFT ANGLE OF ATTACK

A preliminary discussion of aerodynamic performance

AIRCRAFT WEIGHT, LIFT, DRAG, THRUST AND FUEL FLOW

How all these forces interact in steady cruising flight.

AIRCRAFT DESIGN WEIGHTS OR MASSES

Full description of each of the design weights and their role in aircraft design, certification and performance.

Part 2

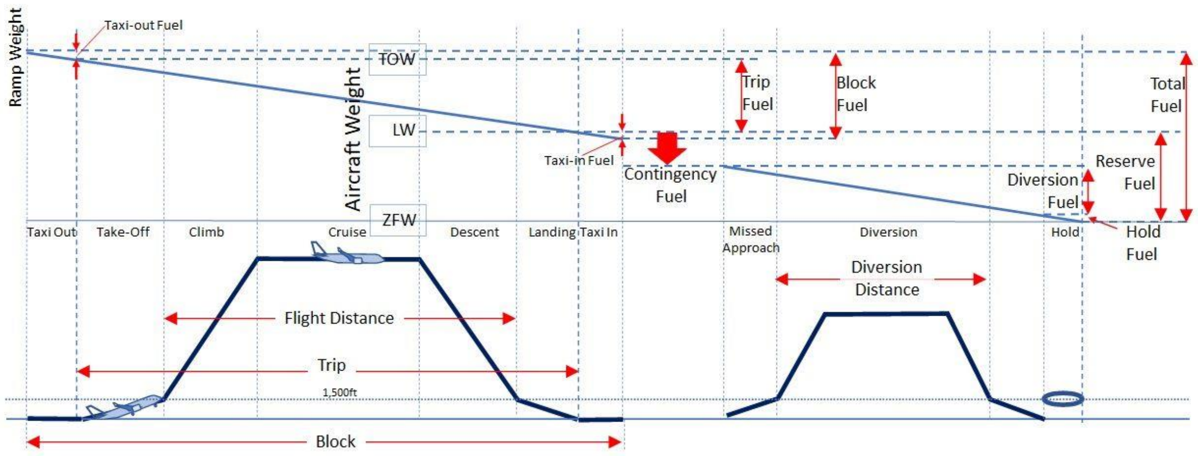
The previous section focussed more on the aircraft (a previous post describes Chapter 4, part 1). Older posts cover previous chapters. Click the '+Follow' to receive notifications of future similar posts from this page.

MISSION DEFINITIONS

Flight Profile component descriptions: taxi, take-off, climb, cruise, descent, approach and land.

It also covers Mission Fuel Policy (or reserve fuel) elements and how they can vary across different jurisdictions, operations and aircraft classes.

'Trip' defined as Power-Up for Take-off until the Aircraft Stops on the Landing Runway
'Block' defined as 'Gate to Gate', i.e. from the start of Taxi Out to end of Taxi In
'Flight Distance' defined as being above 1,500ft, i.e. Climb Cruise and Descent – no distance for Take-Off of Landing
Trip Fuel = Take-Off + Climb + Cruise + Descent + Landing
Block Fuel = Trip + Taxi Out + Taxi In
Reserve Fuel = Contingency + Diversion + Hold
Total Fuel = Trip + Taxi Out + Reserve OR Total = Block – Taxi In + Reserve
Note: **'Taxi In'** fuel is assumed to be taken from the reserves as Reserves are redundant once the aircraft is on the ground



ZFW-RANGE CHARTS - PAYLOAD-RANGE

Full description of typical ZFW-range (or payload-range) charts plus a few oddities (reducing payload with reducing range!). All extended to show how the various design weights affect them and interact.

The focus on ZFW-range, rather than payload-range, serves as an early introduction to the differences between nominal and airline performance levels for the same aircraft.

AIRCRAFT UTILISATION AND PRODUCTIVITY

How aircraft are used, mainly hours flown per year (utilisation) and amount of stuff transported per year (productivity = utilisation x speed x payload).

It is a key element of aircraft operation and drives the finance costs attributed to each flight. It explains the different priorities between different aircraft classes.

DEVELOPMENT/PROGRAMME COSTS

Any Programme achieving commercial success needs to make a profit. 'Keep your eyes on the prize' from Chapter 2

This section explores the fundamental importance of these costs on aircraft design decisions. For example, should a programme target an all-new aircraft or a derivative of an older one? It also discusses the balance of technical risk against required performance levels and the impact of delays on a project's profitability.

OPERATING COST ELEMENTS

A full operating cost method definition for transport aircraft.

Chapter 5 – Top Level Aircraft Requirements (TLARs)

One of Chapter 2's recommendations reflected the importance of setting a good set of requirements.

This chapter discusses the following TLARs, i..e mostly what the customer wants. Other requirements emerge throughout subsequent chapters as required.

GENERAL APPROACH

Understand any baseline or competitor aircraft TLARs with a view to match, surpass or relax them with the new aircraft.

Multiple fuselage lengths?

Ch2 recommendation suggests 'thinking broad, rather than narrow' - applies to many of the following TLARs.

SAFETY

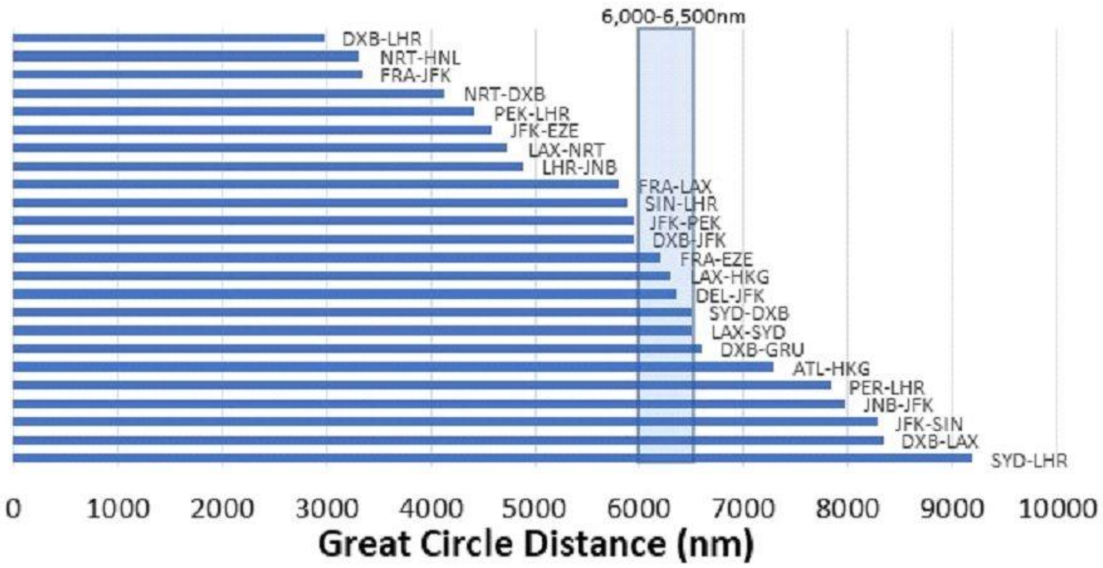
Safety is a given governed by the chosen certification basis.

PAYLOAD

How much and what payload accommodation characteristics (class mix, freight)?

DESIGN RANGE

Which markets is a new aircraft intended to service? It addresses real-world and nominal design range requirements. Real-world 6,000-6,500nm GCD routes need 8,000nm nominal design range requirements.



Key: DXB – Dubai, LHR = London, NRT = Tokyo, HNL = Hawaii, FRA = Frankfurt, JFK = New York, PEK = Beijing, EZE = Buenos Aires, LAX = Los Angeles, JNB = Johannesburg, SIN = Singapore, HKG = Hong Kong, DEL = Delhi, SYD = Sydney, GRU = Sao Paulo, ATL = Atlanta, PER = Perth

ALTITUDE CAPABILITY

What is the minimum acceptable initial cruise altitude following MTOW departure, and what is the maximum operating altitude of the aircraft?

CRUISE SPEED

How fast – this links back to productivity (Chapter 4), but more speed = more energy.

CUSTOMER COMPULSION TO BUY THE AIRCRAFT

Why would a customer buy a new aircraft rather than competitors?

Does it offer:

- substantial economic advantages.
- zero/low environmental emissions.

Or is a government insisting?

It can be a combination of any two or all three.

FIELD PERFORMANCE

What runways are the aircraft intended to take-off from and LAND on?

RELIABILITY

Service interruptions are expensive for the airline and manufacturer (guarantees)

SERVICE LIFE

How many flights and cycles will the aircraft operate during its service life with different airlines. This directly affects structural weight and engine SFC.

ENVIRONMENT

Global mission emissions (CO2 and non-CO2) requirements (emissions) and local airport community rules, e.g. noise and local air quality.

Production energy and materials.

OPERATING INFRASTRUCTURE

Airport and air space limitations on the aircraft design – a new aircraft needs to operate within the existing infrastructure, which cannot change quickly.

MANUFACTURING INFRASTRUCTURE

Assembly halls and the transportation systems to move aircraft components are expensive to establish.

Chapter 6: Analysis Approach to Whole Aircraft Design

It is a dry subject (hence a relatively short chapter) but one critical for effective aircraft design.

All aircraft design textbooks include the necessary components to construct a numerical model of the aircraft. This chapter discusses the underlying philosophy behind the various approaches available to a Whole Aircraft Designer or team.

Chapter 2 includes a recommendation to target consistent methods with the fewest inputs to achieve the targets of the design exercise. Adding more complicated methods with many more inputs ONLY improves the study's results IF the design team define and has confidence in all the inputs and complete control over the analysis (and understands all the functions involved.

The chapter suggests how and where to deploy different levels of method fidelity and, importantly, their potential limitations and pitfalls. It also covers their application for studies of less conventional aircraft configurations.

The importance of the initial calibration of a design system against a well-understood baseline aircraft (ideally multiple aircraft) before tackling a new concept is stressed. Another Chapter 2 recommendation stresses the importance of calibration.

Chapter 6 also explores the importance of understanding the design space relative to numerical optimisation. Aircraft concepts often succeed because they address customer requirements beyond those a numerical modelling system covers. Consequently, trading a minor fuel efficiency degradation for a substantial improvement to a non-numerical aspect wins orders. These trades require JUDGEMENT - the following chapters should guide this.

One challenge of aircraft optimisation is the objective function definition as it introduces biases the optimisation process and resulting aircraft concept.

Chapter 7 Aircraft Performance

This chapter covers mission performance, field performance and various spot-point/flight segment metrics required to assess and communicate an aircraft concept's status against the various performance requirements. They also provide inputs for the operating economics analysis.

MISSION PERFORMANCE

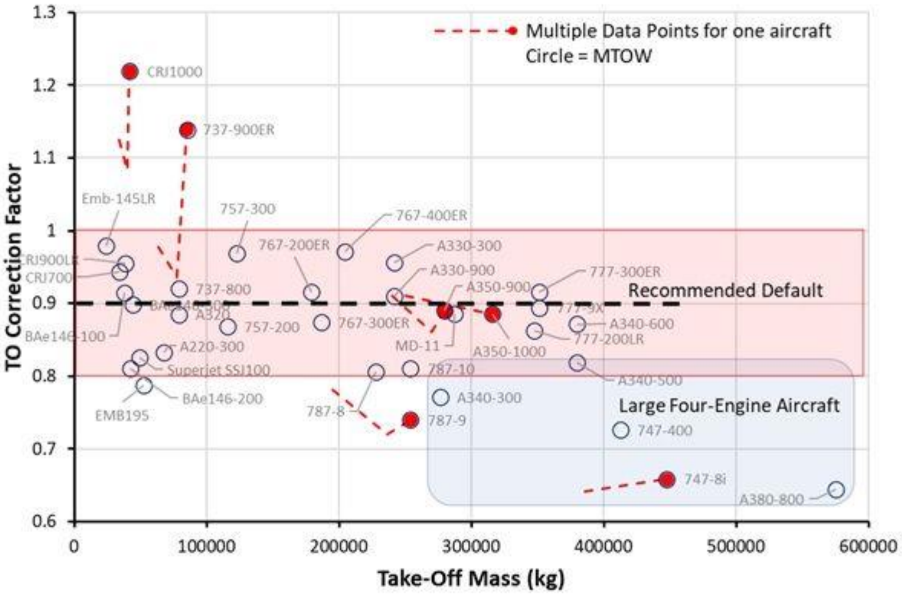
Readers with access to 1st principles aircraft mission modelling can ignore this section, although it might still provide a rapid scoping capability.

For those without access, updates to the venerable Breguet range equation include the effects of lost range (during take-off, climb, descent and landing) and a reserve fuel allowance as a function of mission distance. The latter contains corrections for different diversion distances and contingency assumptions.

It also covers various novel propulsion systems such as LH2 combustion, fuel cell, battery-electric, parallel and series hybrid-electric.

FIELD PERFORMANCE

New methods estimate the take-off and landing field length from readily available design inputs for calibration and concept aircraft. The results (TOFL and LFL) closely match published values for most commercial aircraft (jet and turboprop) and business jets (see image for transport aircraft)—explanations provided for the few outliers.



SPOT POINT AND FLIGHT SEGMENT PERFORMANCE

The aircraft requirements include various performance requirements (not necessarily in the TLARs) that also need checking as they represent corner-point requirements (worst case). Descriptions and methods enable readers to estimate the results.

The segment performance sections provide descriptions, guidance and standard charts to understand and communicate the concept status in design reviews. Charts include Altitude-mass charts and SAR plots.

Fuel calculation for take-off, landing and taxi segments, plus APU fuel flows.

Chapter 8 High-Speed Aerodynamics

It covers the standard troika of profile, lift-dependent and wave drag, providing brief descriptions and the most appropriate methods (in my view) to generate aircraft drag forecasts. The methods include winglet drag effects.

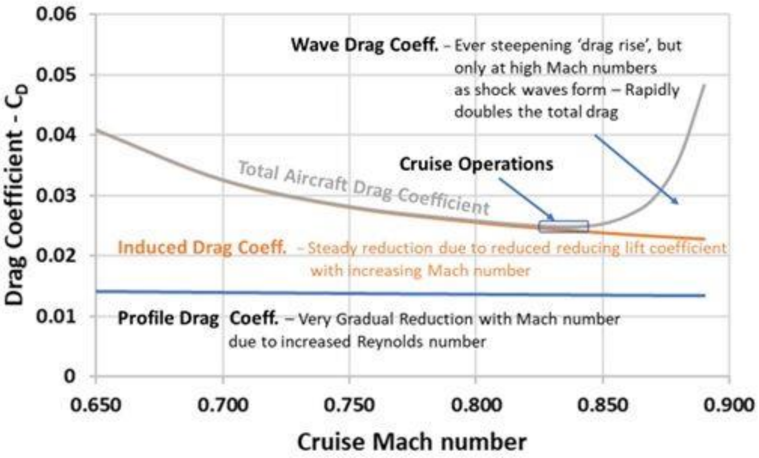
Additional sections discuss 'power-on' vs 'power-off' drag polars, Reynolds number, CG position and aeroelastic effects.

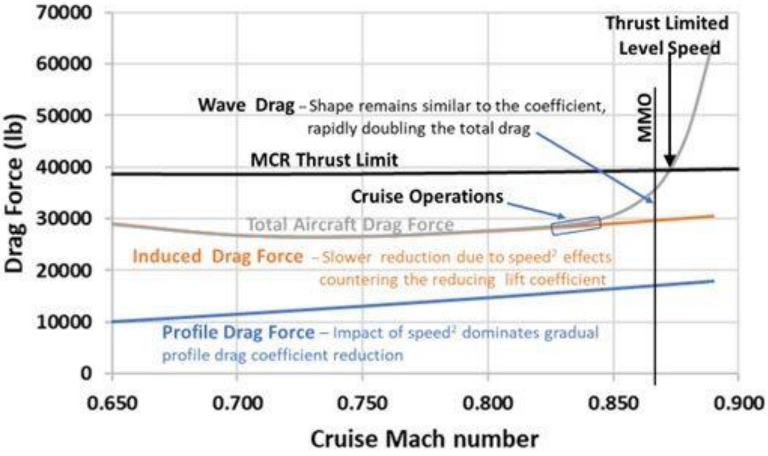
All descriptions build on the concept of lift and drag as energy transfers from the aircraft to the atmosphere.

All methods are simple enough for conceptual design tasks, estimating what should be achievable with a detailed aerodynamic design exercise with high-fidelity tools. All often require some judgement to apply effectively, but always based on a solid calibration basis.

Practical advice describes various aerodynamic characteristic representations, such as the drag and lift/drag polars plotted against the lift coefficient. This chapter also demonstrates the deconstruction of a published drag polar into the three main elements enabling a good calibration of each and the construction of technology trends.

Finally, the chapter includes historical aerodynamic trends and potential future improvements for different aircraft classes, with strategies applicable for less-conventional configurations included.





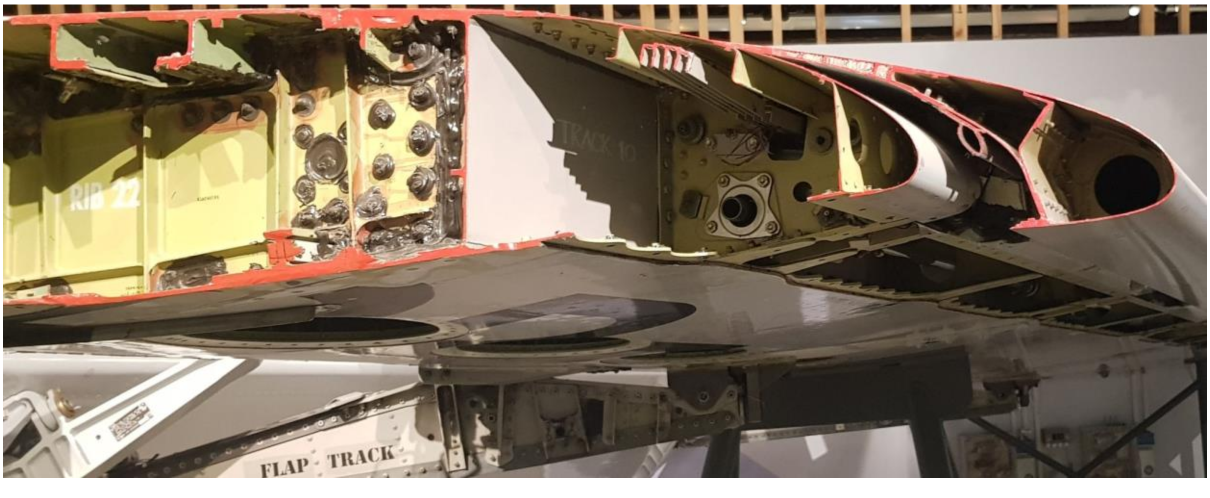
Chapter 9: Structures

A general introduction to aircraft structures.

Types of Structure – Primary, Secondary, Control Surface and Propulsion

Structural Requirements – Ultimate loads, fatigue load spectrum and aging

Types of Load – Static flight, Aeroelastic and dynamic flight, pressurisation, ground manoeuvring, crash and miscellaneous loads



Airframe Material Classes – Metallic, Composites, hybrid materials and additive layer manufacturing

Propulsion System Materials – a very brief introduction

Introduction to structural mass forecasting – General approach to creating representative semi-empirical methods covering the main dependencies, but with available inputs and some judgement. Later chapters provide component-specific mass forecasting methods.

Chapter 10: Propulsion

From a steam engine through piston engines and gas turbines to electric motors.

Propulsion has been and remains the great driver and enabler for aircraft development, converting stored chemical energy into propulsive energy to manage the aircraft's energy state. It counters the energy transferred by the aircraft's aerodynamics, i.e. lift and drag, to the atmosphere.

The propulsion system also powers all aircraft electric, pneumatic and hydraulic systems (Auxiliary Power Units described separately)

The chapter covers the basics of the general thrust equation and theoretical propulsive efficiency.

It explores the fundamental differences between, and limitations of ducted and unducted propulsion systems before exploring the various design points (thrust at a flight condition) for various power-generating options.

Gas turbines feature heavily due to the almost complete dominance of transport aircraft propulsion over the last 70 years. The increasing use of Sustainable Aviation Fuels and future potential hydrogen combustion ensures their continuing relevance.

Gas turbine sizing points and design technical and operational considerations provide the necessary information for an aircraft designer to specify the associated system mass, drag and propulsive efficiency.

The chapter also addresses the current interest in electric motors propulsion with power supplied by batteries, fuel cell or gas turbines. Again, guides for creating parametric models of the energy storage and supply systems permit characterisation of the weight, volume and integration requirements for each.

The power source for the world's first recorded powered flight, a steam engine, only gets a passing mention in historical terms.

Chapter 11: Aircraft Anatomy

This short chapters marks the start of and introduces Part 2 of the book which addresses the various aircraft major components. It discusses the logic for the aircraft break down used for the chapters and weight statement.

Chapter 12: Fuselage Design

The payload accommodation requirements represent the starting point for any aircraft design; payload delivery is the fundamental purpose of any aircraft. Almost all transport aircraft carry their payloads internally within their fuselage, perhaps a centre-body.

Passenger cabin and freight hold dimensions are key drivers of the fuselage design - see image.

Further fuselage internal volume requirements must incorporate crew, aircraft systems, landing gear components, and cabin systems/equipment requirements. It must also ensure suitable external access to all elements and the payload.

Novel propulsion components might also stake a claim for fuselage volume, e.g. hydrogen fuel tanks, fuel cell systems and battery packs.

Finally, the fuselage also connects the rest of the aircraft components, transferring loads around the airframe. Consequently, the wing and empennage integration also feature in the fuselage arrangement. Some configurations also attach their engines to the fuselage.

This chapter describes the design options and trade-offs associated with fuselage arrangements for various aircraft classes.

It also provides a new conventional fuselage mass forecasting method based on extensive calibration data (included) for 6- to >500-seat for reasonably modern aircraft types.

The chapter also provides mass estimation methods for non-conventional fuselages and centre-bodies for hybrid- or blended-wing-body configurations based on airframe company and NASA studies.

The drag component focuses mostly on the fuselage or centre-body profile drag, including any rear fuselage upsweep (especially for military transports).

It also covers fuselage drag reduction options, such as microvane technology to clean up the rear fuselage drag (or reduce the drag associated with improved functionality).

Chapter 13: The Wing

The wing is the critical element of whole aircraft design. It generates a substantial proportion of the profile drag, almost all the lift-dependent drag and, for high subsonic aircraft almost all the wave drag.

It also represents 10-12% of conventional aircraft MTOWs (a greater fraction of the OEW).

Finally, it is the prime sizing component with engine, empennage and some systems sizing points driven by the wing design.

The chapter covers the 4 main wing sizing cases: take-off, top of climb (Initial Curuise Altitude), fuel volume and landing. The latter is often overlooked but critical for almost all modern aircraft familes, even more so for aircraft adding heavy electric and hydrogen energy storage solutions.

It describes the required decisions concerning each wing sizing case, the more important elements of 3D wing design, e.g. cruise lift coefficient (based on sweep and outboard thickness/chord) and aspect ratio (or span).

Although discussed, the role of aerofoil section selection, taper ratio and wing twist are generally assumed inherited from the calibration aircraft (or modified to represent known changes) - aerodynamic specialists should address these in the preliminary design.

Other sections explore the whole aircraft design drivers for including leading and trailing-edge kinks and the wing's typical structural arrangements.

A new wing mass method builds on Prof Torenbeek's comprehensive method in the TU Delft LR693 report). It simplifies some elements but reflects current certification req'ts and adds the effects of new design features typically included by modern aircraft, e.g. load alleviation systems and winglet effects.

Weight calibration data for a wide range of reasonably modern aircraft (included) - the data confirms the methods suitability.

Wing profile drag uses standard flat plate analogy methods with a form factor. Chapter 8 includes the whole aircraft lift-dependent and wave drag methods.

Chapter 14 – Low Speed Aerodynamic Design

Two of the primary wing sizing cases reported in the previous post are a function of the low speed aerodynamic (high lift) system design. i.e. take-off field length and approach speed.

The chapter ultimately enables the reader to generate reasonable and defendable low speed aerodynamic forecasts for new aircraft CTOL and STOL concepts.

Descriptions of the various leading and trailing edge high lift devices and characteristics guide the reader on their choice of high-lift system design and the associated lift coefficient.

It also breaks the linkages used in older numerical methods between flap geometry, deflection and lift coefficient. Modern systems are just too complicated for these methods, e.g. drooping ailerons (and spoilers), continuous trailing edges, constant chord slats, different deflections for each flap segment.

The chapter also provides an historical context and to support modern aircraft design decisions. Early designs strived for ever greater lift coefficients to reduce wing area, while reducing the associated community noise.

The latest large aircraft high-lift systems also increasingly focus on landing performance with simplified systems to reduce weight, community noise, complexity (production and maintenance costs) and, ideally, cruise drag.

Battery-electric and hydrogen energy storage make landing performance even more dominant.

Extensive datasets of aircraft high lift performance data illustrate the whole aircraft compromises used by various aircraft classes, i.e. long and short-haul airliners, business jets, regional and sub-regional turboprops. The descriptions also discuss trends and differences between apparently similar aircraft.

Chapter 15 – Empennage

The chapter primarily focuses on the aircraft's longitudinal and directional stability. The typical contributions to overall aircraft weight (2-5% MTOW) and drag (10-15% total drag) are modest but critical to maintaining safe and controlled flight.

The critical sizing cases for each are discussed to guide whole aircraft decisions. However, the chapter recommends the standard volume coefficient approach for both, but with additional analysis to support the selected values of these coefficients. New analysis methods identify how to adjust a concept's target tailplane volume with headline aircraft attributes (extra to the volume coefficient.

It discusses various planform decisions, with explanations guiding this process — further descriptions cover real-life design empennage surface designs and solutions for practical design challenges.

The discussions cover the apparent 'standard' empennage arrangement used where no other design constraints, i.e. a single vertical fin and a separate horizontal tailplane (or stabilizer) attached to or through the fuselage.

It also discusses the various whole aircraft design choices driving 'T', 'V', 'U', 'H' and 'π' arrangements (vertical are the fins, horizontal represent the stabilizer when looking from behind).

Other sections cover canard configurations, 3-surface arrangements and thrust vectoring for completeness.

Mass and profile drag methods provide the necessary inputs into the whole aircraft design process.

Chapter 16: Landing Gear

The landing gear typically represents about 4% of a transport aircraft MTOW and about 6% of the MLW – it's a function of both. The gear travels up to 80,000-90,000 miles on the ground during its service life, although tyres and brakes are consumables with much more frequent replacement.

The main landing gear also affects other whole aircraft design considerations (all addressed) such as:

i) the wing and fuselage structural mass (taxi and landing loads);
ii) maximum rotation angles at take-off and landing (longer, heavier gear usually improves field performance);
iii) pavement flotation (permission to operate at airports) - increasing MTOW requires more, larger tyres:
iv) the necessary internal volume to store the retracted landing gear (drag) - larger stowed gear creates more drag.

The chapter addresses different main gear arrangements and provides guidance on main gear wheel arrangement and tyre size selection. It also discusses the practical reasons for non-level cabin floors.

The landing gear weight method is the critical expression in whole aircraft design. The chapter modifies a published NASA FLOPS method to include corrections for high specific strength materials, carbon brakes, fixed gear, kneeling gear (from T'beek) and the Boeing semi-levered systems.

It also takes a quick look at tail-dragger configurations and where they provide some advantages for smaller aircraft.

Chapter 17: Propulsion Integration

The propulsion integration is a structural component comprising the nacelle and the pylon/strut (if used).

The nacelle must safely transmit all the engine loads from the powerplant to the pylon through the 'mount' structure. These loads include thrust, weight (under all load conditions) and any static and transient loads resulting from an engine failure.

The nacelle's external surfaces also provide an aerodynamically smooth profile around the powerplant system's external and internal surfaces, minimising the associated drag (or SFC losses).

Their internal volume provides the necessary ventilation and fire safety for all the system components wrapped around the engine.

The nacelle outer surface must also provide easy access to the powerplant for inspection and maintenance. A turbofan nacelle also usually includes a thrust reverser system.

The chapter enables an aircraft designer to size the nacelle to determine its drag contribution to the aircraft.

It includes some top-level mass forecasting methods for the nacelle structure.

Pylon or Strut

Turbofan engines generally include a pylon (or strut) to isolate the propulsion system from the airframe. The pylon looks like a simple component, but the pylon's structural loads are immense, including all those described for the nacelle structure plus the weight of the nacelle.

The pylon also provides a secure pathway between the engine and the airframe for the passage of data, control system commands, electrical power (aircraft systems), fluids (fuel, hydraulic fluid) and high-pressure air.

The chapter describes how to estimate the nacelle and pylons drag contribution.

Finally, it also discusses how novel propulsion systems change the engine installation requirements, although the basics remain similar.

Chapter 18: Aircraft Systems

The various aircraft systems are critical to the safe and economic operation of the aircraft. Their most evident contribution to whole aircraft design is their combined weight (around 10% of the aircraft OEW) and energy consumption (often introducing several % of increased fuel flow). The latter increases the engine SFC due to the energy extracted in hydraulic, pneumatic or electrical forms.

The chapter describes the various sub-systems and their broader effects on whole aircraft design, and provides appropriate weight forecasting methods and typical CG locations reflecting modern aircraft systems.

Where possible, real-world examples back up the guidance and methods.
The sub-systems comprise of the following groupings to approximately match standard aircraft weight statement reports (with some simplification for practical reasons):

Air Conditioning

Avionics & Instrumentation
Auxiliary Power Unit
Electrical Power Generation and Distribution
Fire Protection
Flight Controls – cables, actuators, input devices, etc
Hydraulic & Pneumatic Power Generation and Distribution
Ice-Protection
Anything Else

The chapter also discusses likely development paths for each sub-system and provides guidance on the necessary adjustments to reasonably estimate the weight effects.

Chapter 19: Furnishings and Operator Items

Furnishings and Op items (FOI) convert a fully functioning base aircraft into a vehicle capable of crew operation and safely transporting the payload – it includes the crew.

Both categories include generally readily removable elements, although furnishings often require tools to install or remove them; operator items are more likely carried or wheeled on or off the aircraft, with the crew able to walk on or off.

The combined mass of a passenger aircraft's FOI is considerable, about 15% of the aircraft's OEW. Their mass exceeds the combined system mass or the total installed propulsion systems. Consequently, understanding the FOI mass is critical for aircraft design and an opportunity to save weight.

However, the highly customisable nature of the FOI weight complicates this process. Airframe companies tend to define a base 'specification' level of FOI in their marketing material and define a certain payload/range performance.

Airlines subsequently modify the cabin equipment installed on the aircraft, often substantially increasing the FOI mass to deliver their desired customer (passenger) offering, but reducing the payload/range capability.

Consequently, airlines perform aircraft competitive analysis with these bespoke FOI definitions.

This chapter includes practical mass methods for the specification and airline based on cabin floor area with recommended adjustments for different categories of cabin layouts.

This airline FOI correction also captures any additional mass for optional aircraft systems components not included in the airframe company specification. They are not strictly FOI, but this is the easiest place to account for them during conceptual aircraft design.

Chapter 20 – Whole Aircraft Pre-Design

The 1st chapter in the third part of the book addressing the whole aircraft design process.

Pre-design activities identify the market opportunity and explores how a new aircraft might address it. It also gives an early view of the aircraft concept's (or upgrade's) major attributes and technology shopping list necessary to deliver it.

UNDERSTAND THE COMPETITIVE LANDSCAPE:

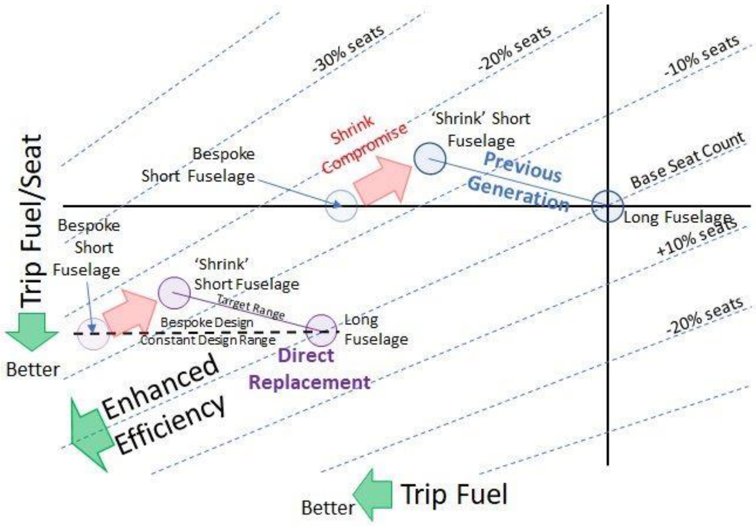
Commercially successful aircraft programmes sell lots of airframes, requiring a business environment where customers will favour the new product.

FAMILY PLAN:

How many variants (different fuselage lengths, roles, etc.) and their market positioning are critical to a programme's commercial success? Cross-hair charts (image), 'zee' charts, shrink, upgauging and range compromises.

PROPULSION TYPE:

The most fundamental aircraft design decision, once settled on a target market.



INITIAL DESIGN SCOPING:

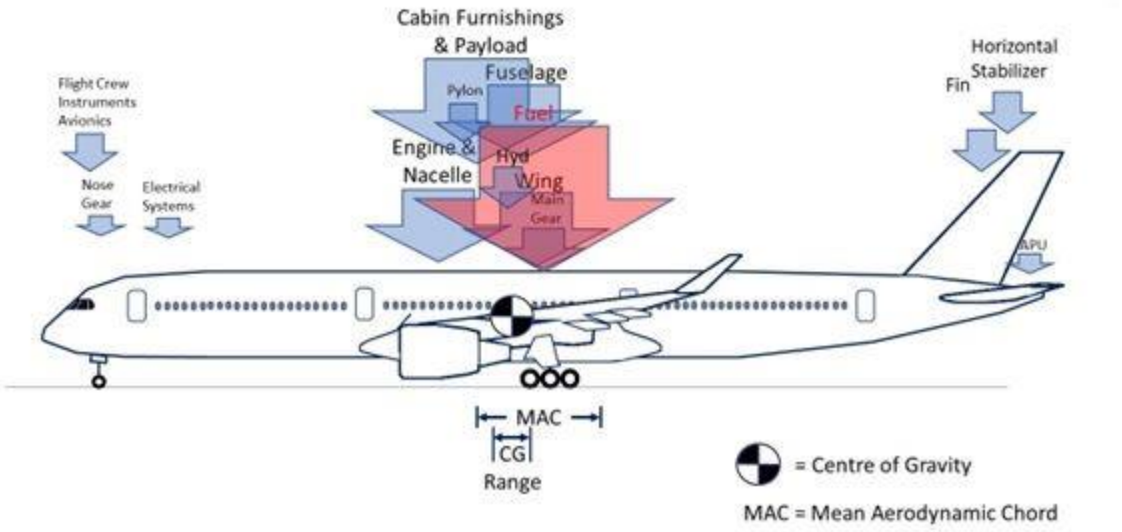
Explores how the new aircraft concept or upgrade will deliver the required technical and commercial performance. What level of aerodynamic, propulsion and weight technology improvement is needed, and how does it affect the technology insertion/risk level required?

The outcome is an initial estimate of the new concepts or upgraded aircraft's major attributes, e.g. design weights, wing area and engine sizing.

Subsequent conceptual and preliminary design revisit these and adjusts them as the design synthesis gains fidelity.

Chapter 22 Aircraft Layout

This chapter adds more detail to the design concept, building on the previously generated initial estimates of the design weights, wing area and engine thrust sizing. The chapters delivers an initial geometrical aircraft layout, with the design synthesis generating the first estimates of the aircraft component weights, drag polar, field and mission performance and operating costs.



The main remaining sizing tasks address the various airframe component geometries. This iterative task also involves critical architectural decisions, such as the wing's vertical positioning, permitting a first aircraft layout.

All require design decisions that are critical to the aircraft design. The fuselage sizing considers how to package the payload accommodation, and the wing geometry blends aerodynamic and structural needs with the possible integration of the main landing gear and propulsion.

The mass and aerodynamic forecasting methods generate the first round of the concept's characteristics necessary to lay out the aircraft configuration that defines the longitudinal balancing (see image) and the vertical positioning of all components.

Finally, the mission and field performance provide the inputs for the operating economics.

Outcome: an initial comparison of the concept against the operating cost improvement requirement and an idea of the level of challenge in subsequent concept refinements.

Chapter 23: Design Iterations and Family Definition

The resulting gap analysis from the previous chapter's initial conceptual design and layout sets the targets for further design iterations.

Generally, the initial concept will not meet some of the Top Level Aircraft Requirements (TLARs) and might exceed others, presenting the designer with choices. Should they accept specific minor differences (change the TLARs) or adjust the aircraft configuration to rebalance the design?

A widespread and significant fuel burn or operating cost improvement shortfall might require additional technology insertion to reach an acceptable concept. The additional costs and risk also need accounting.

A rare concept exceeding the required performance may also accept the situation, or remove certain expensive and higher-risk technologies or design features, i.e. trading worse cash operating costs for lower direct operating costs and reduced programme risk.

The design iterations continue until the concept hopefully converges towards a status satisfying the design team and the TLARs.

At this point, the different MTOW and fuselage length variants need defining, with common wing and empennage planforms, engines, fuselage width and landing gear geometry. The development schedule should also address programme risk and resource optimisation (programme cost).

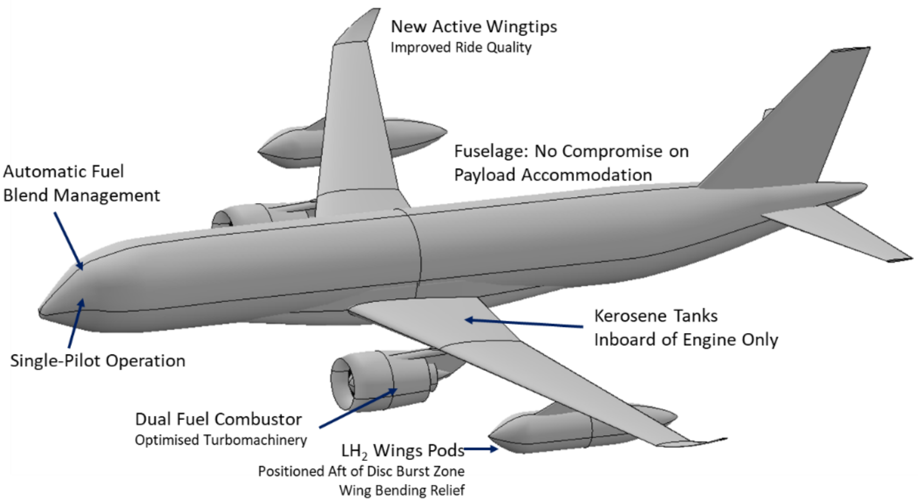
Chapter 24: Report Out

All new concepts need effective reporting for internal design reviews and external sales and marketing material. Success in both is critical for a successful programme, but the requirements are subtly different.

The design reviews are internal 'gates' requiring successful navigation to gain business approval for continued work. The technical attributes must support the business needs of those financing the programme.

Generally, a design review data pack should include:

- Aircraft visualisations:
- A 1-page/slide text summary of the primary aircraft attributes;
- Technology Inclusion – What's new? A 'walkaround chart' (image is fictional)



- Low Risk - what's carried forward from existing products;
- Weight statement (a breakdown of major weight groupings);
- High and Low-Speed Drag Characteristics
- Propulsion Overview
- Payload or ZFW/range chart;
- Fuel burn and operating cost comparisons against other aircraft and the project TLARs;
- Noise (estimate at conceptual stage);

The Sales and Marketing communications usually focus on a higher-level overview with a greater focus on performance on key customer routes and operating cost improvements (all with airline assumptions).

New technology is great, but airlines want the 'so what?' - hence, the name of the book.