

CRANFIELD UNIVERSITY

A. MEDERER

**THE DEVELOPMENT OF A DESIGN METHODOLOGY
FOR LARGE CARGO AIRCRAFT**

SCHOOL OF ENGINEERING

PhD THESIS

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CRANFIELD UNIVERSITY

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PhD THESIS

Academic Year 2007/2008

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The Development of a Design Methodology
For Large Cargo Aircraft

Supervisor:

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This thesis is submitted in partial fulfilment of the requirements
for the degree of PhD

Abstract

Detailed specialist knowledge of pre-design, design, aerodynamics, engine performances and flying performances is necessary for the pre-design of transport aeroplanes.

In this paper, studies are described which provide the main detailed information on the above-mentioned specialist topics.

All studies consists of a problem with a suitable solution and the associated results.

The studies are part of the overall task "Systematic design study on a number of configurations for large aircraft types, in particular for cargo aeroplanes".

As part of the overall task, a design method was developed which is very user-friendly and which is suitable for the design of any aeroplane configurations, in particular for configurations of large passenger or transport aeroplanes.

This thesis version shows how 11 transport aeroplane configurations of very different types can be drawn up.

The configuration results are shown on a scale of 1 : 500 and can be directly used for more detailed studies, as they are based on calculations.

4 of the first 5 transport aeroplane configurations are basic configurations and were scaled between 200 to 1000 t .

Important flying performance characteristics were calculated for the configurations by the use of 8 PC programs additionally developed for this purpose.

Validity studies have shown that the described design method provides useful results.

The main result of the method is that very different transport aeroplane versions can be developed and compared in terms of flying performances.

Currently, only a few very complex design methods are offered elsewhere which have the disadvantage that they are only intended for one aeroplane version.

So far, the design method described in this method is fully applied to the first five configurations.

A next step could be to also investigate the additional six configurations listed here with the method.

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List of designations

Each study phase report has its own list of symbols for the purposes of clarity.

The symbols in the study report summaries are only written in English.

Due to the large number of symbols used, it is useful to produce a special symbol report and separate this from the actual thesis.

This version of the thesis contains a complete symbol report as Appendix B.

List of illustrations

This version of the thesis contains a complete list of all illustrations, diagrams and results table.

Each illustration, diagram or results table is sufficiently described for each report summary, so that a special list of illustrations is not necessary per summary.

References

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CHAPTER 1

Introduction

1.1

1.1 The historical aspect

Hardly more than a hundred years have passed since the Wright brothers made their first officially recognised flights in a motor-driven manned aeroplane on 17. December 1903.

Since then the development of aeroplanes has advanced at a tremendous pace, and the Wrights' little biplane has turned into the large passenger or transport planes of today, which weigh up to 600 t.

After the first successful motorised flights, it was soon realised that aeroplanes were ideal for the transport of people and goods, if suitable places for take-off and landing were available, and if the machines could be made large enough.

In the course of time aircraft factories were built in America and Europe, which manufactured aeroplanes of various kinds.

As a combination of special knowledge and skills was required to build aeroplanes, many firms specialised in certain types of aeroplane, e.g. passenger or transport planes, civil or military aircraft.

Aircraft firms such as Boeing and Lockheed in America, or BAC and Airbus in Europe, to name but a few, are well-known to anyone interested in aeroplanes.

The mass-production of large aeroplanes required mass-production of suitable propulsion units, and so in addition to aircraft factories, firms were set up which built first piston engines and later also jet engines for aeroplanes.

Well-known names among the manufacturers of propulsion units today are General Electric, Pratt & Whitney (USA), Rolls Royce (UK) and SNECMA (France).

As the aeroplanes got bigger, the landing gear for them also became more complicated, because greater weights had to be transported or moved safely.

Therefore in addition to the aircraft firms, suppliers specialising in the development of undercarriages came into being.

Firms like Boeing and Goodyear in the USA or Messier and SNECMA (France) are well-known for this today.

The aim was of course to improve the performance of the aeroplanes more and more, but this was only possible by means of detailed research in the appropriate fields (e.g. aerodynamics, flight mechanics and aeroplane stability)

The aircraft manufacturers could no longer cover this themselves, and so independent research facilities and also institutes at universities were established.

1.1

The safety and reliability of large aeroplanes in the sky and on the ground also necessitated the further development of appropriate flight controls, navigation systems and equipment. New branches of the industry developed to concentrate on these tasks.

Nowadays we take it for granted that airliners cross oceans and operate at altitudes at which cabin pressure has to be kept artificially at the normal level.

A high percentage of the transport of people and goods is now carried out by air.

This proportion will continue to rise, since the main traffic routes on the ground can hardly cope with more, and the need for transport is constantly increasing.

A sensible solution is to build larger aeroplanes, so that more freight can be carried by air.

Passenger or freight aircraft weighing 1000 t and with a load capacity of 250 t could be produced, if the runways and landing strips could be adapted to the needs of these large planes.

1.2

1.2 General requirements

For the design of aeroplanes, large companies have special departments with teams of specialists and engineers with many years of relevant experience.

The design of large passenger or transport aeroplanes in particular requires the combination of comprehensive special know-how such as technical drawing, aeroplane structure design, design aerodynamics, flying performance and flying characteristics calculation for design purposes.

The aeroplane designers generally work with methods which have proven themselves over time and which represent the know-how of the individual company.

The design methods differ considerably from design office to design office, although actually the same basic knowledge has to be applied.

It is natural to attempt to mechanise aeroplane design and develop a design method which is generally valid and can be used in every design office for any aeroplane type.

What type of design method is of interest?

One can develop two very different methods which an aeroplane designer can use:

- 1.) A method which is easier to use, which allows the design of very different aeroplane configurations at the concept stage.
Any design engineer with the normal specialist knowledge can use it immediately.
- 2.) A method which is more complicated to use, which is only intended for the design of a certain aeroplane configuration at the pre-design stage.
Only a specially trained expert can use it, as its application requires experience with the large calculation programs that belong to the method.

How or where can such design methods be developed?

Both methods can actually only be elaborated in an industrial or research project, as their development is costly and time-consuming.

Design method 1.) is also suitable for the subject of a large study thesis, as the necessary costs are kept within limits.

This thesis describes the development of a design method according to point 1.).

The description consists of summaries of study reports submitted as a transcript of study during a course of study at the School of Engineering.

1.3 1.4 1.5

1.3 Research objectives

Initial literature searches and background experience were discussed with the Supervisor and the following objectives were agreed in November 2000:

1. To develop a systematic design synthesis methodology for large cargo aircraft.
2. Validate part, or all of the methodology by means of comparisons with existing large cargo aircraft.
3. Computerise the methodology so that a large number of configurations may be investigated.
4. Extend the methodology to cater for non-conventional configurations.
5. Perform a number of case-studies to investigate a matrix of cargo aircraft requirements in terms of payload, range and speed and note the consequences of civil or military operations.
6. Examine the results of 5 above, to determine trends and make comparisons between configurations in specific roles to determine the best solutions to meet the requirements, if possible.
7. Quantify and discuss any uncertainties and make recommendations for further work.

1.4 Agreed study constraints

1. Payload range between 50 → 400 tonnes.
2. Cruise Mach nos. between 0.65 → 0.85
3. Concentrate on 4 basic configurations, but quantitatively discuss a wider range.
4. Civil transport aircraft should consider JAR25 airworthiness requirements, whilst military should consider DEF-STAN 00-970.
5. Consider existing and future environmental requirements.
6. "Best Solutions" from objectives will include:-
 - improved loading and unloading
 - best to meet volume, density and cargo shape requirements
 - most suitable to minimise direct operating costs
 - meet performance and field length requirements

1.5 Plan for communications

1. Frequency of trips to Cranfield - twice per year. Possible short-courses.
2. Ad-hoc visits when JPF is in Munich.
3. Reports 1-2 months frequency + monthly letters. One week after receipt of English version of report
 - Telephone conversation
 - Fix up time with JPF secretary
4. Requirement for progress meetings and seminars - tie-in with 6-monthly visits

CHAPTER 2

Literature search and description of the state of the art

2.1

2.1 Literature review

A long study of literature in books and in internet listings for design methods for aeroplanes, in particular for large transport aeroplanes, produced the following results:

- There is a large number of good books and university lectures on aeroplane design, but only a few established methods which relate to overall design.

Usually only the basic design elements such as the fuselage, wings, stabiliser and engine are described and several example calculations carried out.

Often overall aeroplane design concepts are also presented, but the associated performance figures are omitted.

- There are some computer-aided design methods which cover overall pre-design, but they are very complex and only apply to one aeroplane version.
(see Appendix C).

Well-known books and documents

J. Roskam (books)

Airplane Design Parts I through VIII (v. 1 - 8)

Introduction to Aircraft Design

(Cambridge Aerospace Series)

E. Torenbeek (Author)

Synthesis of Subsonic Airplane Design

Cornelis Bil

Development and Application of a Computer-based System for Conceptual Aircraft Design

Delft University Press, 1988, Ph.D. Thesis

Aircraft Design Software Rev.

Discussions:

The AAA (Advanced Aircraft Analysis) code

Started out as a computerized version of Roskam's eight-volume text:

Airplane Design, Parts I - VIII

2.1

Brief discussion of the references quoted in Appendix C:

Multi-disciplinary aircraft design with the program system PrADO

- Collection of sub-programs (FORTRAN) for the specialist fields involved in the design
- The sub-programs are organised in four program levels and linked with each other via a data management system (DMS).
- In addition, a FORAN-Compiler JAVA and a commercial graphics program AMTEC Tecplot
- Four program levels
 - 1st level: data input and presentation of results
 - 2nd level: individual calculation/parameter variation/optimisation
 - 3rd level: iterative design process
 - 4th level: problem-oriented program libraries
- Use of external programs
- At the beginning search for a feasible configuration for the specified design task
- Specified technological basis
- Configuration optimisation (example 100-seater)
Working mode parameter variations
- DOC-analysis with variable or constant aircraft price
- Growth limits of freight aircraft
Conventional freight aircraft, flying wing freight aircraft
- Evaluation of the use of liquid hydrogen as fuel for smaller regional commercial aircraft
- PrADO is not limited to the design of aircraft.
Evaluation of traffic systems such as cars, maglev trains, ships
- Prognosis methods for system parameters with effects on economic of commercial aircraft
- Design method for gliders on the basis of the design program PrADO

2.1

Design methods and aircraft design

- Task-neutral design process

Clarification, conception, design, detailing

- Set of construction documents represents milestone and result of the design process

- Modified phases

- Problem analysis or pre-phase activities, construction of a database

- Concept phase, to scale 3D view

- Development phase

Construction documents, durability approval, production concept

- Modified milestones

- Technical specification

- Payload, mission profile, performance parameters, airworthiness category

- Technical concept

- Roll-out, maiden flight

- Iterative procedure in 2 stages

1st stage: basic parameters, limited detail resolution

2nd stage: analysis of the results of stage 1, higher accuracy

- Modularisation of the design process, concept phase

Weights, stability/control/regulation, propulsion, flight performances, geometry,

loads/structure, aerodynamics, costs

- Linking of modules

Database has central position

2.2

2.2 State of the art at the start of the programmes

State of the art

Whereas the tools of the aeroplane designer in the 1960s were still the drawing board, compass and pencil and the parameters for the design were essentially based on the experience of the designer and his design team, today the situation has improved. Due to the rapid developments in computer technology, the aeroplane designer now has computer screens available to him with connections to a PC or mainframe computer on which he can produce his designs.

The computers may have design programs installed (CAD, CAD LT) and all design details are available to the designer on the screen.

Apart from the basic design programs, more complex design and layout programs are also available today for computer systems. However, these are mostly owned by institutions or companies and may usually only be used there. Appendix C contains examples of these.

In general, the method by which the designer creates his designs has only essentially changed in terms of the aids or tools used. The relevant experience and documents which the designer possesses still play a major role today.

However, it is conceivable that the procedure for designing aeroplanes will also be standardised, in particular in relation to different aeroplane categories.

A first step towards standardising the procedure for designing aeroplanes is, for example, that designs are created in rough, as before, on the drawing board etc. and are only then transferred to the computer screen, where they can be improved, modified and also scaled as required.

As computers are usually connected to a printer or plotter, a particular design can be immediately produced on paper to the required scale.

New approach

The second step towards standardising the procedure for designing aeroplanes could be to use a fully developed method for which a description is available.

The experience of the designer and other results from relevant reports or calculations are then used for comparison with the results provided by the method.

This study comprises a new approach for a design method, its development and application.

This method was developed in particular for different configurations of large passenger and transport aeroplanes.

CHAPTER 3

Research plan

Research plan

Research plan no. 1:

In the original research plan, points are listed which have mostly been dealt with and for which the main results are documented in the summaries of this work.

The list of tasks are summarised in tables 1 to 3.

All work completed is marked in the right-hand margin with a cross (x) and next to it the numbers of the study phases containing the relevant results.

Figure 1 shows the flow chart for research plan no. 1:

A flow chart was produced for the original research plan in which related main points are summarised in blocks.

The numbers of the study phases which deal with the relevant contents of the blocks are listed to the right of these blocks.

The original research plan has a total of 18 main study points, of which 14 have been dealt with so far.

Therefore, there are still 4 main points to be dealt with in order to complete the overall task.

Main study points not yet dealt with are not marked in the right hand margin.

Sub-points not yet dealt with are marked (-) in the right hand margin.

All studies already dealt with or not yet dealt are listed in the flow chart and provided with the relevant report numbers, but those not yet dealt with have a (-) next to the numbers.

Research plan

TABLE 1 TASKS 1 TO 4

WORK TASK	ACTIVITY	STUDY PHASE
1.	Determination of Possible Wing/Fuselage Arrangements (Schematic Diagrams) for Large Transport/Cargo Aeroplanes	x 3, 4
1.1	Known and Tested Wing/Fuselage Systems <ul style="list-style-type: none"> a. Aircraft with Tail Stabiliser (regular) b. Aircraft with Front Stabiliser c. Tandem Arrangement of the Wings d. Aircraft with Front and Tail Stabiliser e. Flying Wing <ul style="list-style-type: none"> a. through e. with Single Fuselage a. through c. with Double Fuselage (stabiliser boom) e. with Single Fuselage or without Fuselage 	x 3
1.2	Hardly Known or Unknown Wing/Fuselage Systems <ul style="list-style-type: none"> f. Aircraft with Three Wings of the Same Size g. Aircraft with Rhombus-Shaped Wing Arrangement 	x 4
2.	Determination of Potential Cargo-Compartment Arrangements for the Wing/Fuselage Systems Listed under 1. (Schematic Diagrams)	x 3, 4
2.1	Cargo Compartment in Main Fuselage	
2.2	Cargo Compartment in Double Fuselage	
2.3	Cargo Compartments in the Wing	-
2.4	Cargo Compartment in External Containers	
3.	Selection of Four Basic Configuration Types for Further, more thorough Design Examinations, taking certain Selection Criteria into Account, e.g.:	x 3
3.1	Aircraft with Tail Stabiliser and Single Fuselage, Cargo Compartment in the Fuselage	
3.2	Aircraft with Front and Tail Stabiliser and Single Fuselage, Cargo Compartment in the Fuselage	
3.3	Aircraft with Tail Stabiliser and Double Fuselage, Cargo Compartment in the Main Fuselage	
3.4	Aircraft with Tandem-Arranged Wings, Cargo Compartment in the Main Fuselage	
4.	Determination of the Potential Engines for Large Transport/Cargo Aeroplanes	x 7
4.1	Propeller Engines (piston engine)	
4.2	Turboprop Engines (PTJ)	
4.3	Regular Turbojet Engines (TJ)	
4.4	Fan Engines (jet turbine with front or aft fan)	

Research plan

TABLE 2 TASKS 5 TO 12

WORK TASK	ACTIVITY	STUDY PHASE
5.	Differences in Performance and Particularities of these Engine Types Speed, Flight Altitude	x 7
6.	Possible Number of Engines Regarding the Basic Configuration Types Examined Failure Safety, Design Solutions	x 3
7.	Wing and Stabiliser Design for the Basic Configuration Types	x 3, 6
7.1	Aerodynamic Aspects, Profiles, Flap Systems	
7.2	Constructive Considerations, Firmness	
7.3	Design Solutions	
8.	Fuselage and Cargo-Compartment Design for the Basic Configuration Types	x 2, 3
8.1	Arrangement and Size of the Cockpit	-
8.2	Location, Size and Accessibility of the Cargo Compartment	
9.	Landing Gear Design for the Basic Configuration Types	x 8
9.1	Single Wheel Configuration	-
9.2	Tandem Wheel Configuration	
9.3	Comparative Considerations	
9.4	Landing Gear Concepts	
10.	Design Concept and Layout of the Basic Configuration Types	x 3, 8
10.1	Individual Configurations	
10.2	General Description of the Configurations with regard to their Advantages and Disadvantages	
11.	Scaling of the Basic Designs	x 11
11.1	Different Cargo-Compartment Sizes with Equal Flying Performance Data (equal mission profile; mission profile = flight altitude, distance, ascent, descent)	
11.2	Different Mission Profile with Equal Freight Quantities (load is equal, cargo compartment is equal)	
11.3	Dimensions of Cargo Compartment and Mission are Different Scaling: Determination of the Main Aircraft Data (geometrical data, engine data, flying weight)	
12.	Determination of the Flying and Transport Function of Large Cargo Aeroplanes, Various Categories	x 12
12.1	Determination of a Corresponding Mission Profile	
12.2	Appropriate Take-Off and Landing Distances	
12.3	Appropriate Cargo Load	
12.4	Appropriate Individual Performance Aspects (horizontal flight speed, rate of climb, ceiling)	

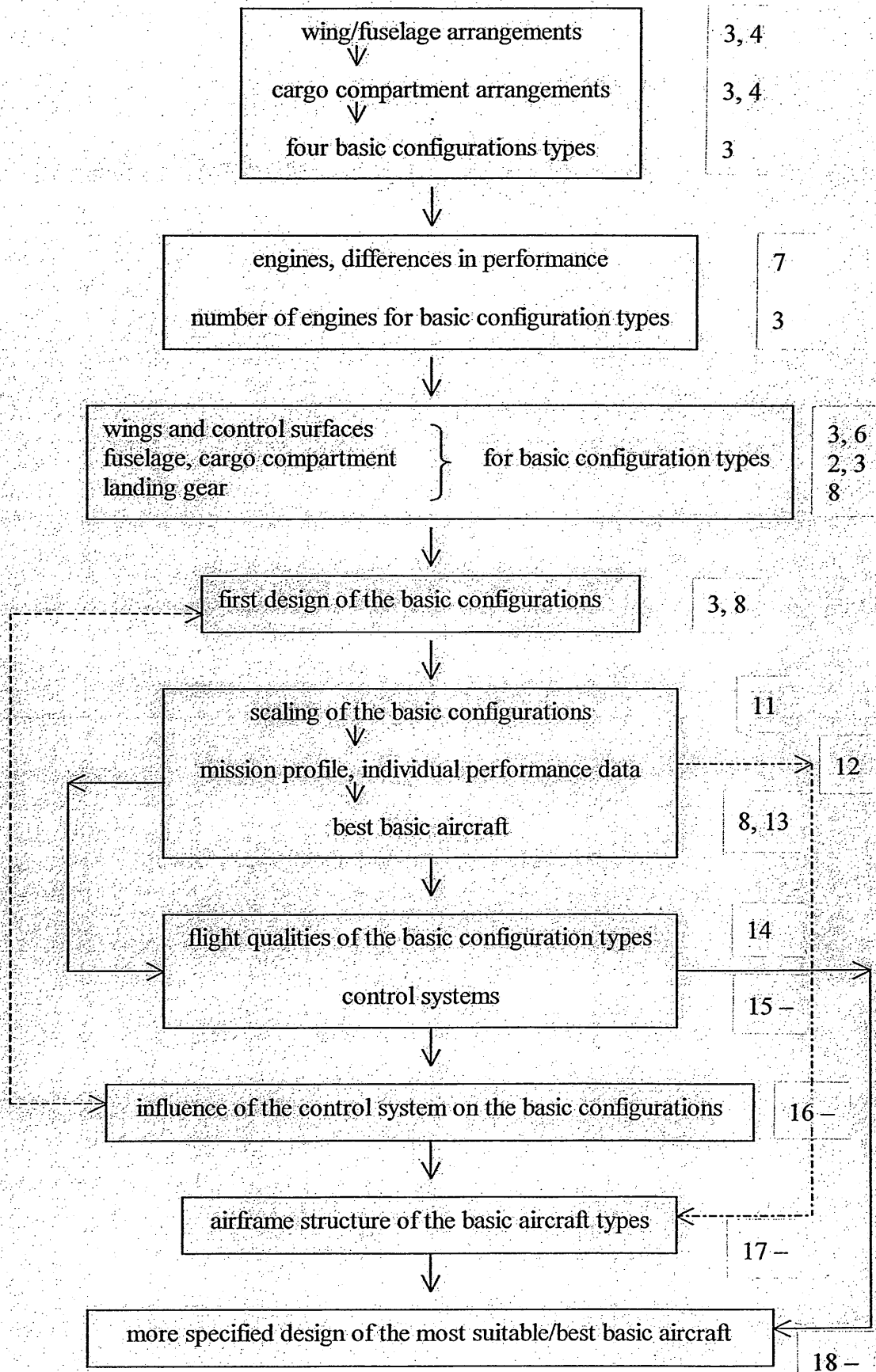
Research plan

TABLE 3 TASKS 13 TO 18

WORK TASK	ACTIVITY	STUDY PHASE
13.	Which of the Scaled Basic Designs meets the Mission Values under 12. best?	x 8, 13
13.1	Differences of the Four Basic Concepts in Performance Respecting Task 12.	
13.2	Amount of Fuel, Overall Weight	
13.3	Other Differences Influencing a Decision Loading and Unloading, Size of the Aircraft	-
14.	Flight Qualities of the Four Basic Configurations	x 14
14.1	Flight Quality Characteristics, Corresponding Particularities of the Basic Aeroplanes, e.g. Mass Moments of Inertia	
14.2	Important Quality Values of the Longitudinal and Directional Stability	x
15.	Control System under Consideration of the Transport Function	
15.1	Which Flight Control System could be used?	
15.2	Comparison of Traditional/Electronic Control Systems Functioning Method, Handling, Construction Concepts	
16.	Impact of the Control System on the Four Basic Configurations	
16.1	Modification of the Geometrical Data and the Flying Weight, the Size of the Stabiliser when using an Electronic Control System	
17.	Airframe Structure of the Four Basic Configurations	
17.1	Design of the Airframe (mesh structure)	
17.2	Construction Concepts of important Partial Zones	
17.3	Application of the Finite Element Method for Determining Critical Constructional Zones	
18.	Detailed Design of the Presumably most Appropriate Basic Aeroplane	
18.1	Wing and Stabiliser Layout	
18.2	Fuselage Design and Cargo-Compartment Layout	
18.3	Design of the Engine Accommodation	
18.4	Concept and Layout of the Landing Gear	
18.5	Cockpit Design Arrangement of Seats, Controls, Glasswork	
18.6	Design Concept and Layout of the Flight Controls Pitching, Yawing, Rolling	

Research plan

Flow Chart



CHAPTER 4

Development of the design methodology

4.1

Development of draft methods, preliminary comments

Comparison of current and new draft methods

Current draft method

Advantages:

An almost unlimited number of concepts for transport aeroplanes can be shown, as these concepts were recorded or outlined only very roughly.

Disadvantages:

A concrete preliminary draft for a selected concept is obtained only after lengthy, detailed drawing studies.

The comparison of different concepts or preliminary drafts therefore involves great effort.

The weight calculation for a selected preliminary draft also requires great effort and requires a large, suitable computing program.

Calculations or comparisons of flight performances of different concepts are only possible after producing corresponding preliminary drafts and also require a large, suitable computing program.

New draft method

Disadvantages:

Only a limited number of concepts for transport aeroplanes can be shown, as all drafts use the same draft basis, which has limits.

Advantages:

A concrete preliminary draft for an initial concept can be obtained after only brief computing and drawing studies, which can then be varied in accordance with the limited type and number of concepts.

The resulting preliminary drafts or configurations are already realistic and can be used for more detailed, more accurate configuration studies.

As a result of the basis of the draft, the weight calculation for a selected preliminary draft is easy.

Calculations or comparisons of flight performances of different concepts are directly possible on the basis of the preliminary drafts produced and are also useful, as they all use the same draft basis.

However, a smaller, suitable computing program is useful for this.

4.1

Assumptions

The main feature of this method is that at the beginning a total aeroplane hold is designed which consists of 8 to 10 cubic spatial elements, which are aligned in accordance with study section 2.

The hold is dimensioned by assuming a mean specific weight for the total of the cubic spatial elements, so that a weight results for the total aeroplane hold which equals the maximum take-off weight

For a transport aeroplane configuration, wing and tail unit areas are arranged on the total hold so that a normal aeroplane configuration is produced as a basic configuration.

It is now possible to arrange the wing and tail unit areas both on the total hold and in combinations with each other which are different to the basic configuration in order to obtain new configurations, as described in study section 3.

Apart from this configuration design, it is also possible to increase the number of wing and tail unit areas, for example to double them, and arrange them accordingly on the total hold so that more new configurations are produced – see study sections 3 and 4.

With all transport aeroplane configurations designed in this way, the individual wing and tail unit areas should always be of the same size as in the basic configuration.

With regard to flying performance this means:
with the same total aeroplane hold, each configuration has a different flying performance or flying speed and range.

Limitations

The main feature of this method is that at the beginning a complete aeroplane hold is designed which consists of 8 to 10 cubic spatial elements, which are aligned in accordance with study section 2.

Wing and tail unit areas are arranged in relation to individual hold elements, where no dimensions are specified.

As a certain ratio between the wing and tail unit depths and the length of the hold or width of the individual hold elements is necessary for a realistic transport aeroplane design, only a limited number of wing or tail unit areas can be arranged on the total aeroplane hold behind or on top of each other.

This limits the number of different transport aeroplane configurations.

According to the studies in study section 3, 5 useful familiar configurations are possible if only one main fuselage is assumed.

According to the studies in study section 4, 6 additional useful, little known or unknown configurations are possible if, in addition to a main fuselage, two smaller secondary fuselages are provided to carry the tail units.

4.1

Selection of the appropriate draft basis for the overall task

The following comments refer to the short versions 1 to 11 of the PhD thesis.

The original research plan is based on the current draft method.

Initial considerations demonstrated already that the development of comparable transport aeroplane concepts with the associated preliminary drafts with the current method take up a great deal of time and that it is therefore more advantageous to change the research plan slightly and work with the new method.

For this reason, two preliminary studies were carried out, which served to define a draft basis for the new draft method.

Study phase 1:

Draft basis, part a

Maximum weight of transport aeroplane and payload
Approximate flight performances for this

Study phase 2:

Draft basis, part b

Size of transport aeroplane and payload
Volume for this with the aid of specific weights

Development of transport aeroplane concepts using the draft basis

In study phases 3 and 4, the design of the concept or configuration for different aeroplane types is developed and described in detail.

Flow-chart of the new draft method

In study phase 5, the draft method is described with a flow-chart of the associated work phases.

The “influence diagram” shown on page 3 is of particular importance here, which shows the dependence of the aeroplane draft sizes on input parameters.

Application of the new draft method

To improve understanding of the method, a description of the application for concept 1 or configuration 1 from study phase 3 is attached to this paper.

Based on this description, the draft method can also be understood and followed in detail.

4.1

Possibilities for the design basis

1. Weight of aeroplane and payload

This design basis is especially suitable for designing different aeroplane configurations.

There are no special restrictions regarding the choice of propulsion.

2. Engine and propulsion category

This design basis is used when the aeroplane type is largely defined or when only one certain engine is possible.

The design engineer designs an aeroplane configuration around a defined propulsion drawing.

3. Wingspan and fuselage length

This design basis is used, for example, when the aeroplane to be designed must be accommodated in a defined hangar.

Overland aeroplane transport may also be a decisive factor in selecting this design basis.

4. Take-off rolling distance and wing loading

This design basis is used when the take-off and landing possibilities of defined airports are restricted as a result of the runway length.

As studies have shown, the take-off and landing rolling distance also depend on the wing loading.

5. Flying height and flying speed

This design basis influences the wing and propulsion unit design.

For a high flying height at a medium flying speed, a large wing surface is required.

A high flying speed requires engines suitable for this speed.

4.2

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Section 1

Concerning study phase 1

Problem and solution:

The transport capacity of large passenger or transport aeroplanes primarily depends on the main weight shares on which the maximum take-off weight of each of these aeroplanes is based.

The following definition exists:

$$W_{\max} = W_E + W_{\text{Pay}} + W_{\text{Fuel}} \quad (1)$$

If the main weight shares are related to the maximum take-off weight, the following applies:

$$1 = W_E/W_{\max} + W_{\text{Pay}}/W_{\max} + W_{\text{Fuel}}/W_{\max} \quad (2)$$

Equation (2) states that the sum of the 3 main weight ratios must be 1.

The weight ratio $W_{\text{Fuel}}/W_{\max}$ can now be expressed as a function of the specific fuel consumption:

$$W_{\text{Fuel}}/W_{\max} = f(\text{SFC}) = \text{SFC} \cdot (C_D/C_L) \cdot T \quad (3)$$

If $f(\text{SFC})$ is inserted in (2), a relation is produced which contains the flight time T .

$$1 = W_E/W_{\max} + W_{\text{Pay}}/W_{\max} + \text{SFC} \cdot (C_D/C_L) \cdot T \quad (4)$$

If equation (4) is resolved according to T , then:

$$T = (1 - W_E/W_{\max} - W_{\text{Pay}}/W_{\max}) \cdot (1/\text{SFC}) \cdot (1/(C_D/C_L)) \quad (5)$$

R/V can be inserted in (5) instead of T and an equation can be created for the range of passenger or transport aeroplanes:

$$R = (1 - W_E/W_{\max} - W_{\text{Pay}}/W_{\max}) \cdot (1/\text{SFC}) \cdot (1/(C_D/C_L)) \cdot V \quad (6)$$

The formulae (5) and (6) state that transport aeroplanes of all weight classes have the same flight time and range if

- a) the ratios $W_E/W_{\max}$ and $W_{\text{Pay}}/W_{\max}$ are the same for the aeroplanes
- b) the reciprocal lift/drag ratio during flight is the same for the aeroplanes
- c) the flight speed is the same for the aeroplanes
- d) the specific fuel consumption of the engines of the aeroplanes is the same.

Section 1

Equation (6) describes the overall range spectrum of different transport aeroplanes.

To calculate the flight time and range of a selected or hypothetical aeroplane, the relations (5) and (6) must be adapted to this case:

$$T = (1 - (W_E/W_{\max})_{\text{aeroplane}} - (W_{\text{Pay}}/W_{\max})_{\text{aeroplane}}) \cdot (1/\text{SFC})_{\text{aeroplane}} \cdot (1/(C_D/C_L))_{\text{aeroplane}} \quad (7)$$

$$R = (1 - (W_E/W_{\max})_{\text{aeroplane}} - (W_{\text{Pay}}/W_{\max})_{\text{aeroplane}}) \cdot (1/\text{SFC})_{\text{aeroplane}} \cdot (V/(C_D/C_L))_{\text{aeroplane}} \quad (8)$$

The known range diagram of a selected aeroplane is obtained by making the weight ratio $(W_{\text{Pay}}/W_{\max})_{\text{aeroplane}}$ variable in the equations (7) and (8).

The flight time and range equations developed in this way only apply to $\text{SFC} = \text{constant}$ and $V = \text{constant}$.

Results:

A range diagram was calculated for an example aeroplane with formula (8), see page 3.

For the fixed aeroplane variables in (8), the following data were assumed:

$(W_E/W_{\max})_{\text{aeroplane}} = 0.5$ (mean value for large aeroplanes)

$\text{SFC} = 0.8 \text{ lb}/(\text{lb} \cdot \text{h})$ (mean value for turbo-jet engines)

$V = 600 \text{ kph} = 166.67 \text{ m/s}$ (flying height 7 km)

$C_D/C_L = 0.05$ (minimum value)

$W_{\max} = 200 \text{ t}$

The range of a transport aeroplane is maximum according to formula (8) when:

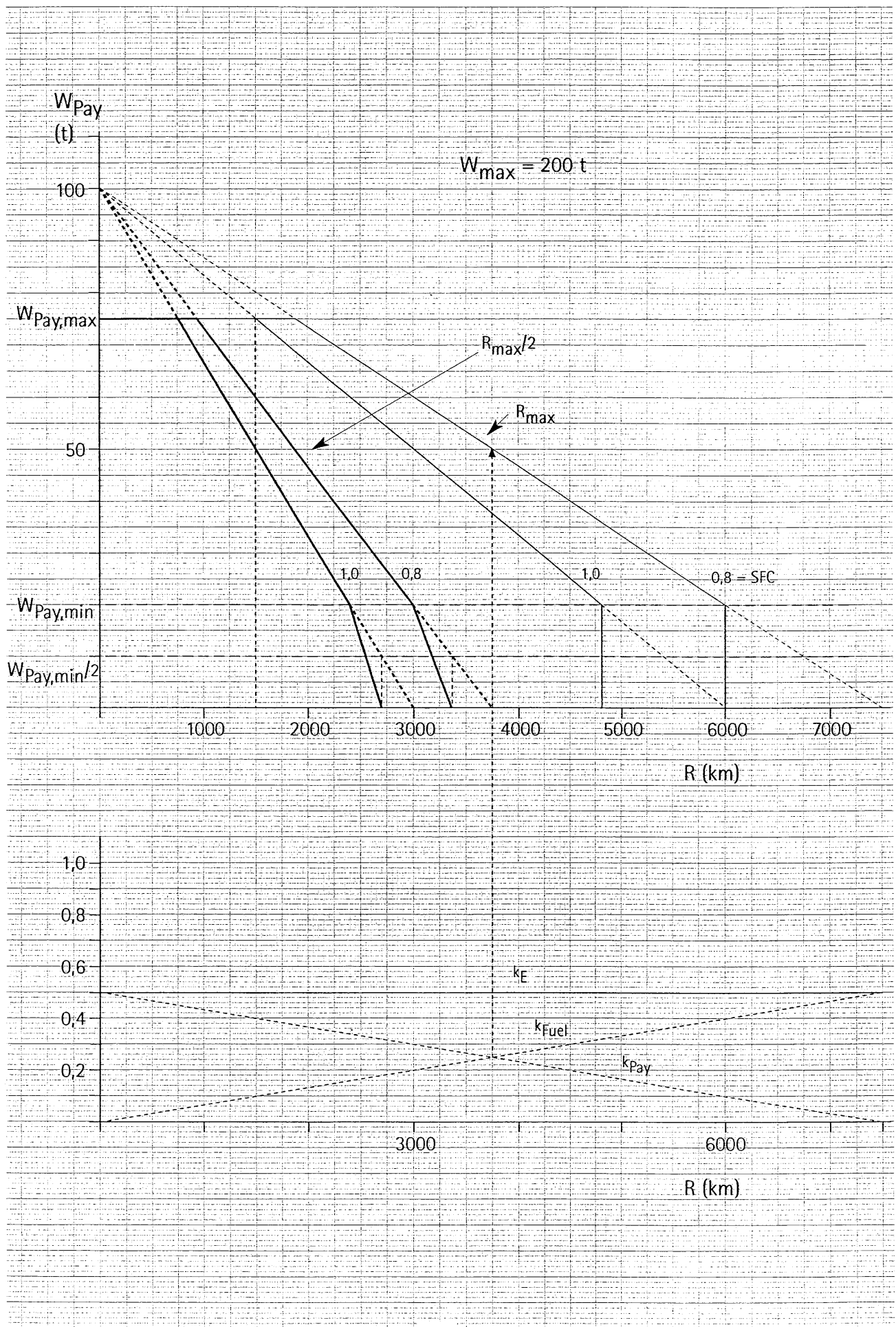
$$(W_{\text{Pay}}/W_{\max})_{\text{aeroplane}} = 0$$

The range of a transport aeroplane is zero according to formula (8) when:

$$(W_E/W_{\max})_{\text{aeroplane}} + (W_{\text{Pay}}/W_{\max})_{\text{aeroplane}} = 1$$

The flight time associated with different payload ratios can also be determined by dividing R by V.

Section 1



Section 2

Concerning study phase 2

Problem and solution:

With large passenger and transport aeroplanes, the passenger space or hold occupies a higher percentage of the total aeroplane volume than with most other aeroplanes. Due to the size of the hold of transport aeroplanes, it is seldom cubic in shape but is longer than it is high or wide and adapted to the aeroplane fuselage.

The shape of the fuselage of large transport aeroplanes depends both on the requirements of aerodynamics and on the size and quantity of the payload.

A mathematical relation can be drawn up for the conversion of a cubic to a non-cubic hold, which is more elongated than the cubic one but is less high or wide:

$$h_0^3 = h^2 \cdot l = h^3 \cdot (l/h) = h^3 \cdot (1/k) \quad (9)$$

The relation (9) can be converted into four useful hold parameters:

$$h^3/h_0^3 = k \quad (10)$$

$$h/h_0 = k^{1/3} \quad (11)$$

$$l^3/h_0^3 = 1/k^2 \quad (12)$$

$$l/h_0 = 1/k^{2/3} \quad (13)$$

With (10), the volume h^3 of a cubic hold element can be determined for a given hold elongation coefficient k if the total payload volume h_0^3 is known.

With (11), the height or width h of the cubic hold element can be determined for a given hold elongation coefficient k if the height h_0 of the overall cubic hold is given.

With (12), the volume l^3 of an overall cubic hold can be determined for a given hold elongation coefficient k if the total payload volume h_0^3 is known.

With (13), the height or width l of the overall cubic hold can be determined for a given hold elongation coefficient k if the height h_0 of the overall cubic hold is given.

Section 2

The height l of the max. overall cubic hold is equal to the length of the non-cubic, elongated hold.

The height, width and length of the hold adapted to the aeroplane fuselage is defined with the formulae:

$$h = b = h_0 \cdot k^{1/3} = h_0 \cdot (h/l)^{1/3} \quad (14)$$

$$l = h/k = h/(h/l) \quad (15)$$

$$l = h_0 \cdot (1/k^{2/3}) = h_0 \cdot (1/(h/l)^{2/3}) \quad (16)$$

The equations developed for the space of the actual payload in the aeroplane can also be applied to the space which a transport aeroplane occupies overall.

For this, an overall aeroplane volume $h_{0, \text{aeroplane}}^3$ is defined and an aeroplane fuselage height $h_{\text{aeroplane}}$ as well as an aeroplane fuselage length $l_{\text{aeroplane}}$ (without nose and tail) assumed.

In addition to the formulae (9) to (16), the following then also applies:

$$h_{0, \text{aeroplane}}^3 = W_{\max} / W_{\text{spec, aeroplane}} \quad (17)$$

With the specified maximum take-off weight $W_{\max}$ and mean specific weight of the transport aeroplane $W_{\text{spec, aeroplane}}$, formula (17) gives the overall aeroplane volume and then the dimensions for the aeroplane fuselage corresponding to $W_{\max}$ can be found with the formulae (10) to (16).

Results:

The functions of k described by (10), (11), (12) and (13) are shown on page 3.

For a transport aeroplane concept, the overall aeroplane hold and the actual cargo space were dimensioned.

This was based on the following data:

$$W_{\max} = 200 \text{ t}$$

$$W_{\text{spec, aeroplane}} = 0.2 \text{ t/m}^3$$

$$h_{0, \text{aeroplane}}^3 = 1000 \text{ m}^3$$

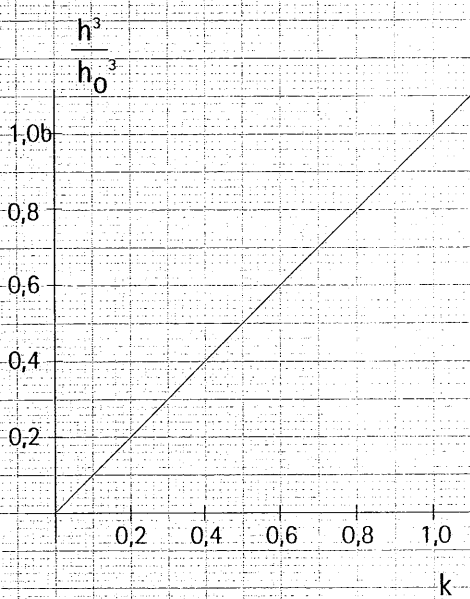
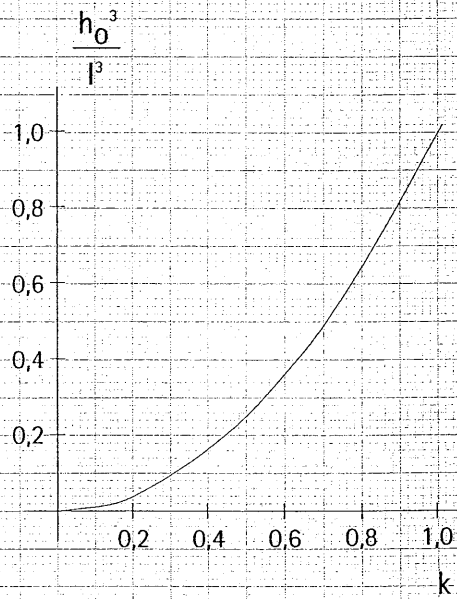
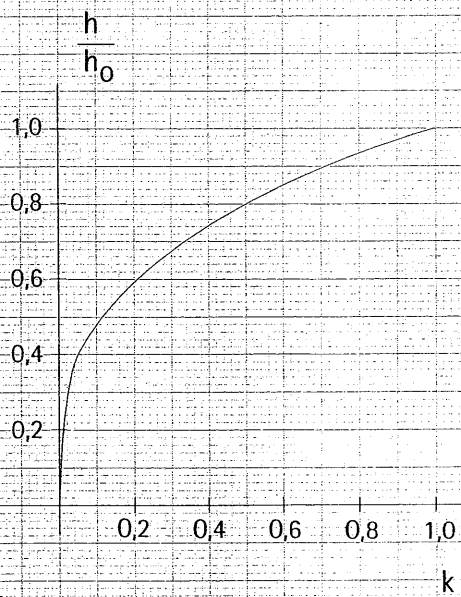
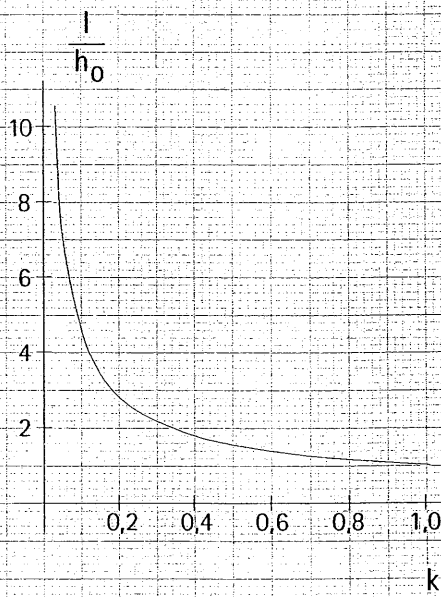
$$h_0^3 = (1/4) \cdot h_{0, \text{aeroplane}}^3 = 250 \text{ m}^3$$

$$k_{\text{aeroplane}} = 1/8$$

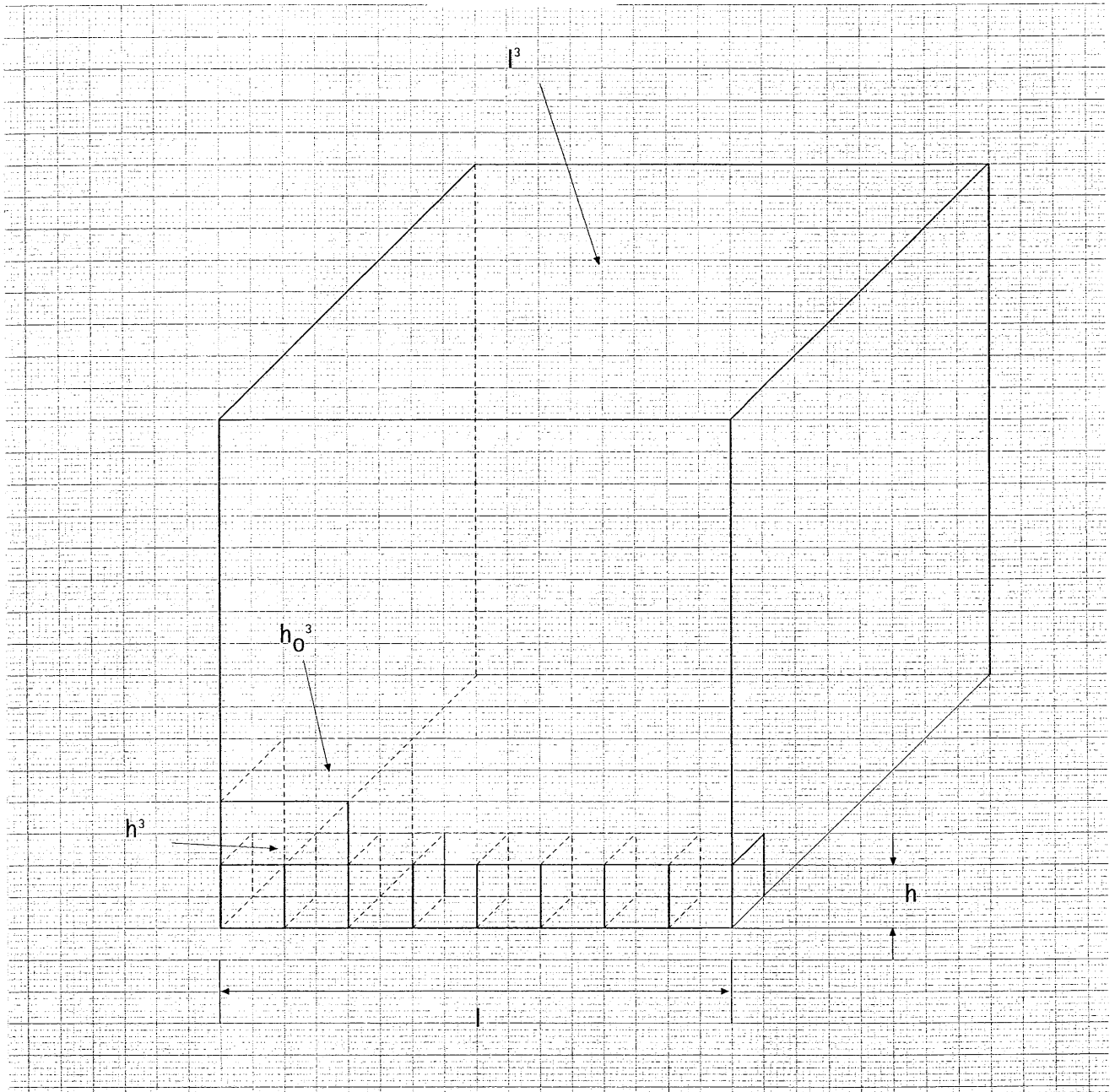
$$k = 1/2$$

With these data, the formulae (10) to (16) give the dimensions for overall aeroplane hold and cargo space shown on page 5.

Section 2



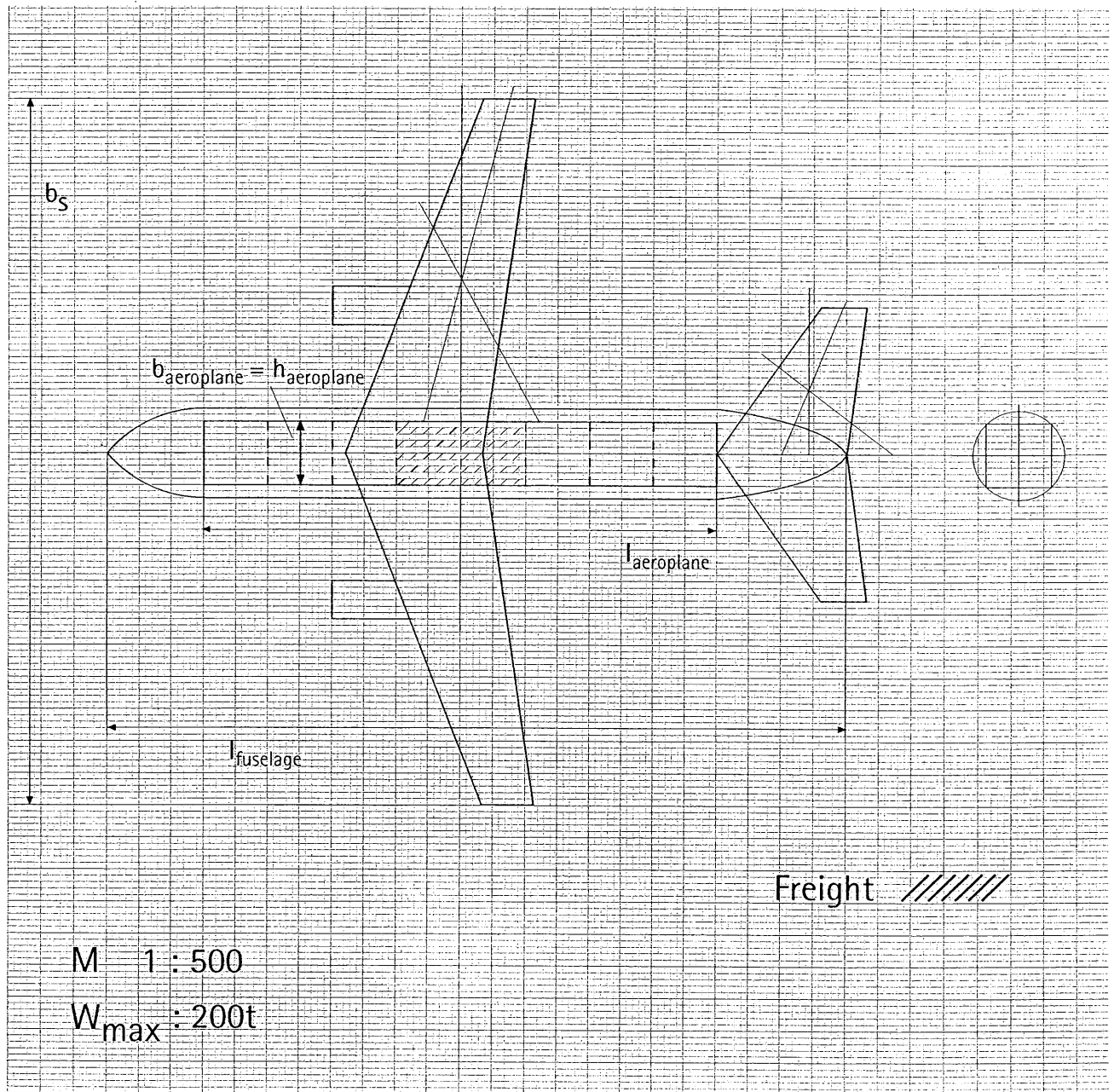
Section 2



- h^3 = min. freight volume
- h_o^3 = max. freight volume
- l^3 = max. overall volume of the freight
- h = height and width of the freight
- l = length of the freight
- $k = h/l$ = aspect ratio number (1/8)

Section 2

Schematic diagram 1
Transport aircraft



Section 3

re. study phase 3

Problem and solution:

Designs of aeroplanes with different configurations are normally based on configuration concepts which are still very rough and do not contain any calculations.

Only after further, more precise graphic studies in which calculations are also made (determination of the wing and tail surface, estimation of weight) can it be shown whether the original form of the elaborated aeroplane design is at all possible or what it should really look like.

The initial ideas discussed in study phases 1 and 2 enable another better way of designing aeroplanes, in particular large passenger or transport aeroplanes!

It begins with a configuration based on the calculations described in studies 1 and 2. These calculations show the designer, for example, the expected flying time and range as well as the aeroplane size or fuselage dimensions even before more exact studies are carried out.

As studies 1 and 2 do not contain any wing, tail or engine calculations, these are added as soon as the size of the initial configuration has been defined.

Different configurations can now be developed by arranging the individual aeroplane parts (main aeroplane elements) of the initial configuration differently with relation to the fuselage and also to each other. It is also possible to increase the number of individual aeroplane parts in a design.

In this way, 5 familiar basic aeroplane configurations and 6 less familiar or unfamiliar aeroplane configurations can be developed with only one initial configuration.

The familiar basic aeroplane designs are:

- aeroplane with rear tail (1)
- aeroplane with front tail (2)
- aeroplane with front and rear tail (3)
- aeroplane with tandem arrangement of wings (4)
- aeroplane without the normal tail, wings only (5)

Study phase 3 only deals with the familiar basic aeroplane designs.

Section 3

Wing and horizontal tail calculation for transport aeroplane design (1):

$$S = W_{\max} / (W_{\max}/S)_{\text{aeroplane}} \quad (18)$$

$$(W_{\max}/S)_{\text{aeroplane}} = (\rho/2) \cdot V_{\min}^2 \cdot C_{L\max} \quad (19)$$

$$b_s = (A_s \cdot S)^{1/2} \quad (20)$$

$$A_s = 1 / (\pi \cdot k) \quad (21)$$

$$\lambda_s = c_{ts} / c_{rs} \quad (22)$$

$$S_s = \overline{V_0} \cdot (S \cdot c) / l_{s,s} \quad (23)$$

$$b_s = S_s / ((c_{ts} + c_{rs})/2) \quad (24)$$

$$\lambda_s = c_{ts} / c_{rs} \quad (25)$$

Optimum lift coefficient of the wing:

$$C_{L\text{opt}} = (C_{D0}/k)^{1/2} \quad (26)$$

Sweep of wing and horizontal tail:

$$\phi_s = \text{measured to } (0.5 \cdot c)\text{-line}$$

$$\phi_{s,s} = \text{measured to } (0.5 \cdot c)\text{-line}$$

Fuselage and engine pod calculation for transport aeroplane design (1):

$$l_{\text{fuselage}} = l_{\text{aeroplane}} + 3.5 \cdot h_{\text{aeroplane}} \quad (27)$$

$$l_{\text{engine}} = (l/d_l)_{\text{engine}} \cdot d_{l,\text{engine}} \quad (28)$$

$$d_{l,\text{engine}} = (4 \cdot S_I/\pi)^{1/2} \quad (29)$$

$$S_I = (C_D/C_L) \cdot W_{\max}/(\rho \cdot V_{\text{opt}}^2) \quad (30)$$

Section 3

Results 1:

Assumptions for transport aeroplane design (1):

The wing and the horizontal tail were dimensioned for the overall aeroplane hold shown on page 5, section 2 based on the following data:

$$W_{\max} = 200 \text{ t}$$

$$V_{\min} = 240 \text{ km/h} = 66.67 \text{ m/s (at flying height 0 km)}$$

$$C_{L\max} = 1.8$$

$$k = 0.0415$$

$$\lambda_s = 0.4$$

$$—$$

$$V_0 = 1.44$$

$$c = 7.25 \text{ m}$$

$$l_{s,s} = 27 \text{ m}$$

$$\lambda_s = 0.35$$

$$C_{D0} = 0.015$$

$$\varphi_s = 15^\circ$$

$$\varphi_{s,s} = 22^\circ$$

With these data, the formulae (18) to (26) produce the transport aeroplane configuration 1 shown on page 6 if the wing area is allocated to the overall aeroplane hold in such a way that the connection line of the centres of gravity of the outer wing surfaces halves this hold.

In configuration 1 the horizontal tail area begins directly behind the overall aeroplane hold, which defines the horizontal tail lever arm.

The sweep of the horizontal tail slightly extends the lever arm compared with a tail without sweep.

The wing position depends on the centre of gravity of the aeroplane, which was designed in such a way that it is on the connection line of the centres of gravity of the outer wing surfaces.

Assumptions for transport aeroplane designs (2), (3), (4) and (5):

The transport aircraft configurations 2, 3 and 5 shown on pages 7, 8 and 10 have the same wing and horizontal tail surfaces (where applicable) as in configuration 1, but the surfaces are arranged differently to the overall aeroplane hold.

Section 3

The connection line of the centres of gravity of the outer wing surfaces is further back in configurations 2, 3 and 5 than in configuration 1.

In configurations 2 and 3 there are two hold elements, in configuration 5 one hold element.

In configuration 2 the horizontal tail surface halves are attached to the side of the front fuselage of the transport aeroplane (front tail).

The connection line of the centres of gravity of the outer wing surfaces has a distance to the connection line of the centres of gravity of the horizontal tail surface halves of four hold elements, which defines the horizontal tail lever arm here.

Configuration 3 is the same as configuration 2 apart from a second horizontal tail surface, which begins directly behind the overall aeroplane hold.

Configuration 5 does not show a horizontal tail surface. This is replaced by two vector jets, which are fitted to the engine pods.

In configurations 2, 3 and 5, the wing position is defined by the centre of gravity of the aeroplane, which was assumed to lie on the connection line of the centres of gravity of the outer wing surfaces, as in configuration 1.

The transport aeroplane configuration 4 shown on page 9 is characterised by two wing surfaces of the same size on an overall aeroplane hold extended at the front.

Each wing surface is the same size as that in configuration 1.

The extension of the overall aeroplane hold is one hold element.

The position of the two wing surfaces in relation to the overall aeroplane hold corresponds to that of the wing and horizontal tail surface of configuration 2.

The two connection lines of the centres of gravity of the outer wing surfaces are four hold elements apart.

The centre of gravity is designed in the middle between the wing surfaces.

Section 3

Results 2:

Assumptions for transport aeroplane design (1):

For the overall aeroplane hold shown on page 5, section 2, the fuselage length and the engine pod size were defined based on the following data:

$$l_{\text{aeroplane}} = 40 \text{ m}$$

$$h_{\text{aeroplane}} = 5 \text{ m}$$

$$W_{\text{max}} = 200 \text{ t}$$

$$V_{\text{opt}} = 600 \text{ km/h} = 166.67 \text{ m/s (at flying height 7 km)}$$

$$C_D/C_L = 0.05 \text{ (minimum value)}$$

$$l/d_f = 2.9$$

With these data, the formulae (27) to (30) produce the fuselage length and the engine pod size of the transport aeroplane configuration 1 shown on page 6.

Assumptions for transport aeroplane designs (2), (3), (4) and (5):

The transport aeroplane configurations 2, 3 and 5 shown on pages 7, 8 and 10 have the same fuselage length and engine pod size as in configuration 1.

The transport aeroplane configuration 4 shown on page 9 has a fuselage length which is one hold element longer but the same engine pod size as in configurations 1, 2, 3 and 5.

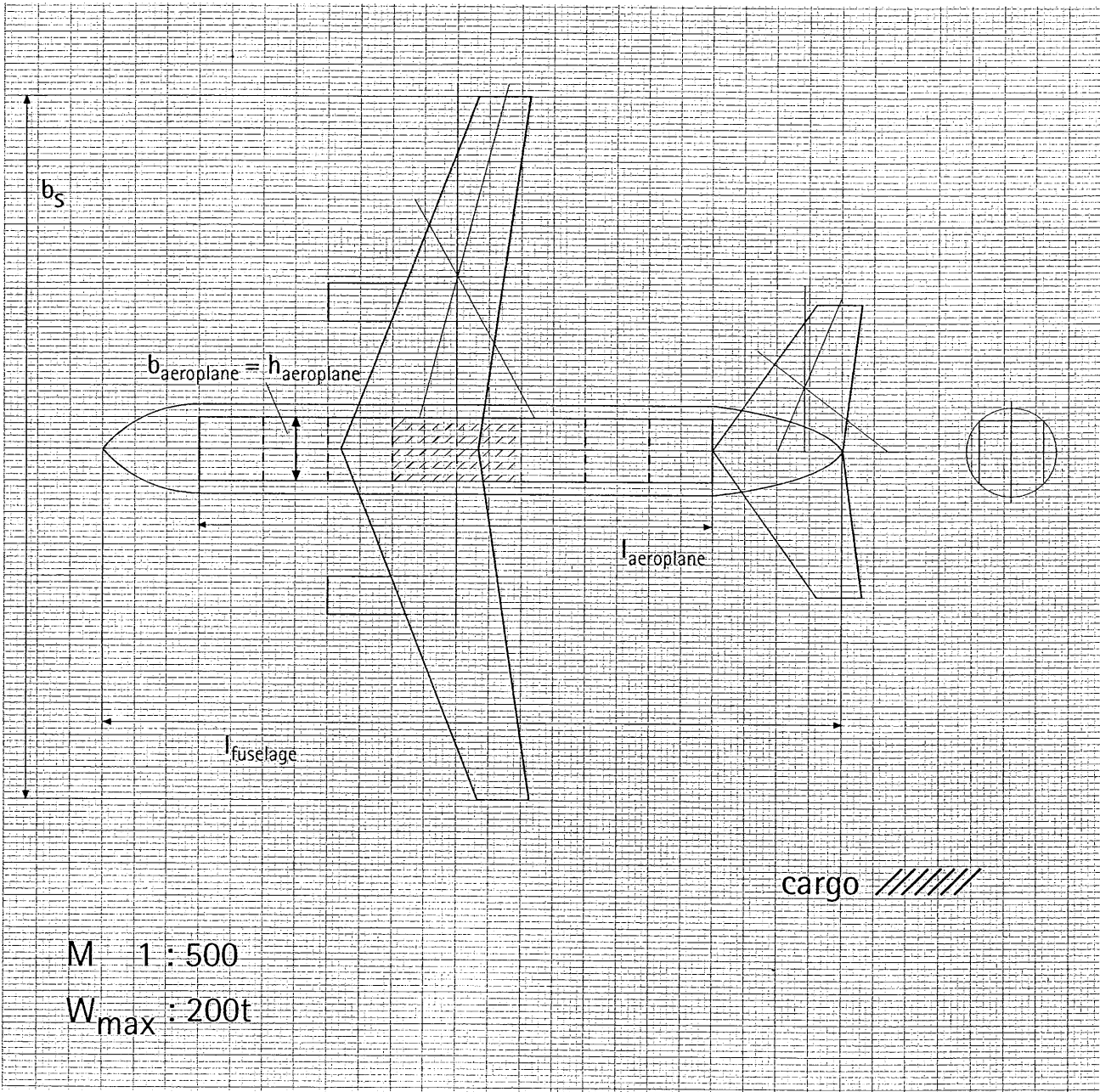
In transport aeroplane configurations 1, 2 and 3, the engine pods are situated directly in front of the connection line of the centres of gravity of the outer wing surfaces, but in configurations 4 and 5 directly behind.

The different arrangement is defined by the planned position of the centre of gravity in the individual configurations.

The positioning of the engine pods on the wing in spanwise direction is only provisional.

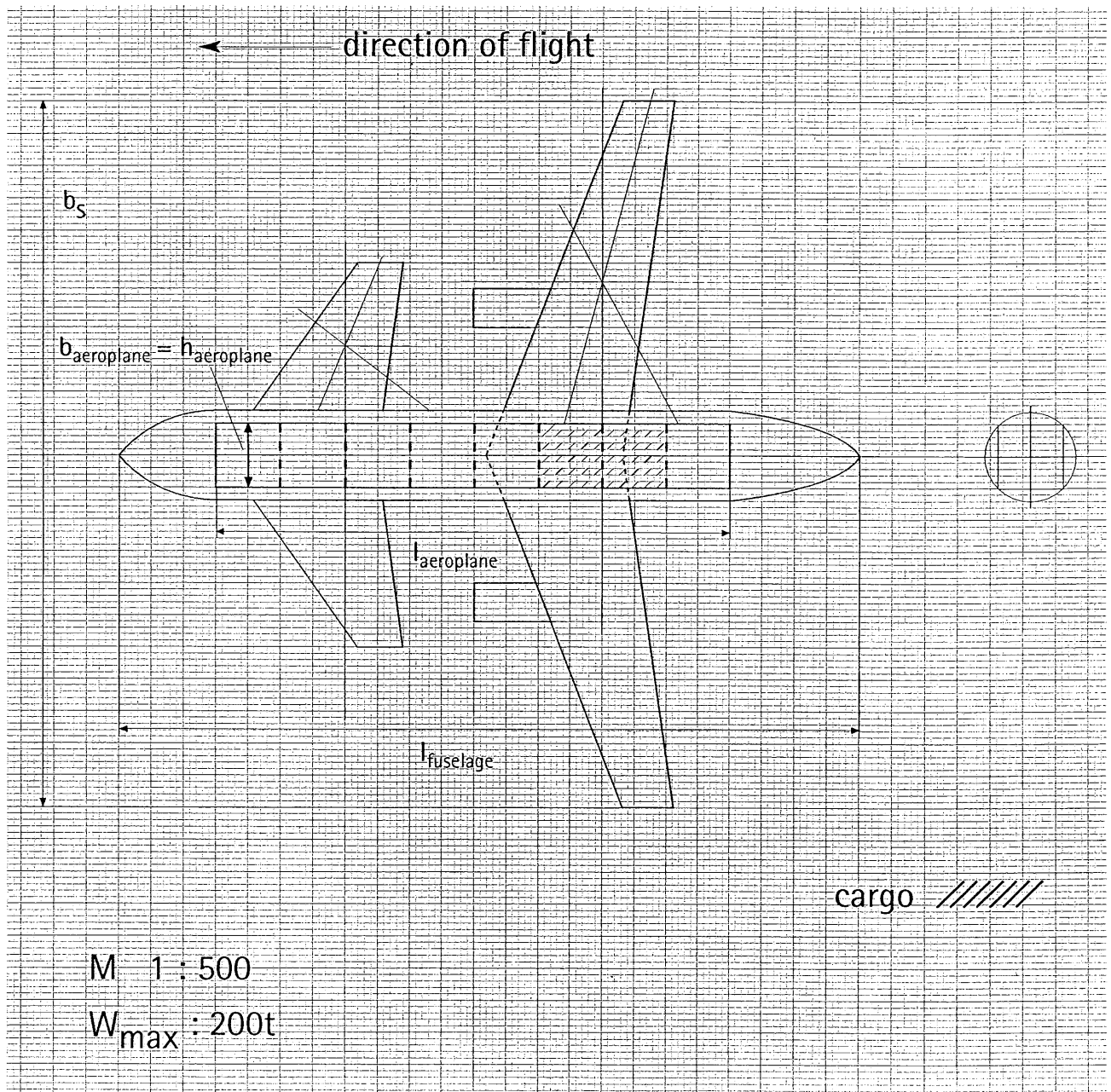
Section 3

Schematic Diagram 1
Transport Aircraft



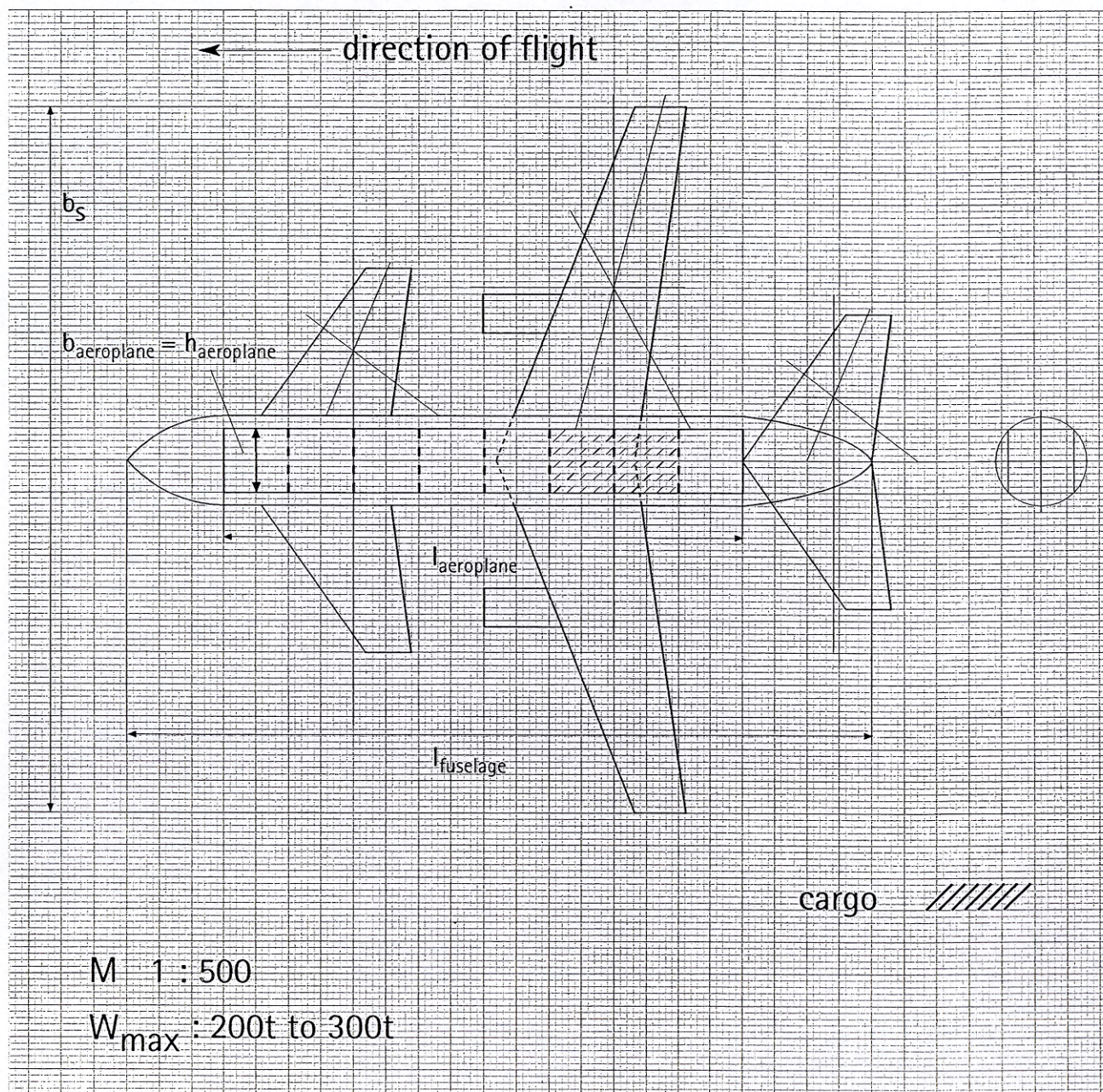
Section 3

Schematic Diagram 2
Transport Aircraft



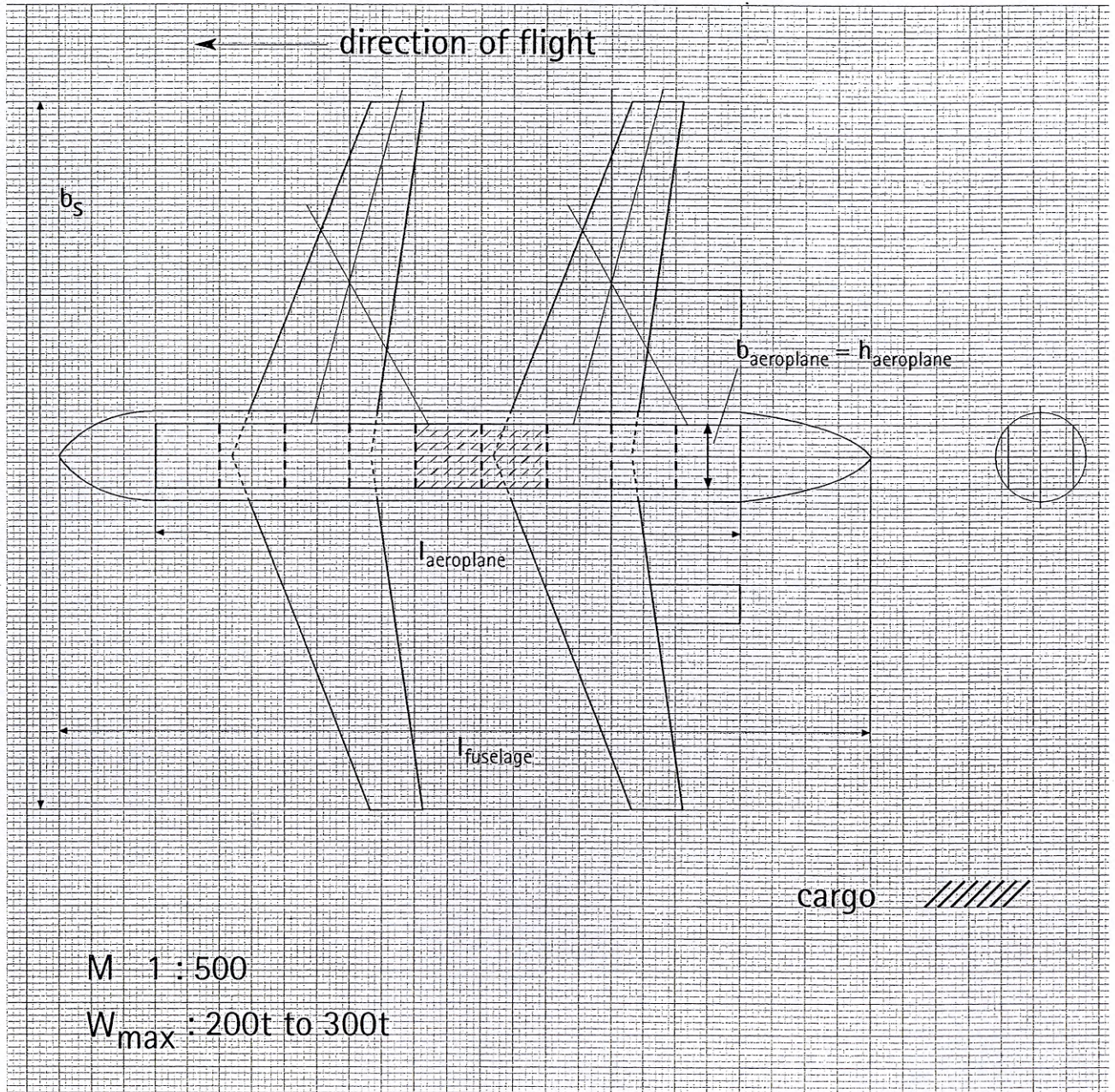
Section 3

Schematic Diagram 3
Transport Aircraft



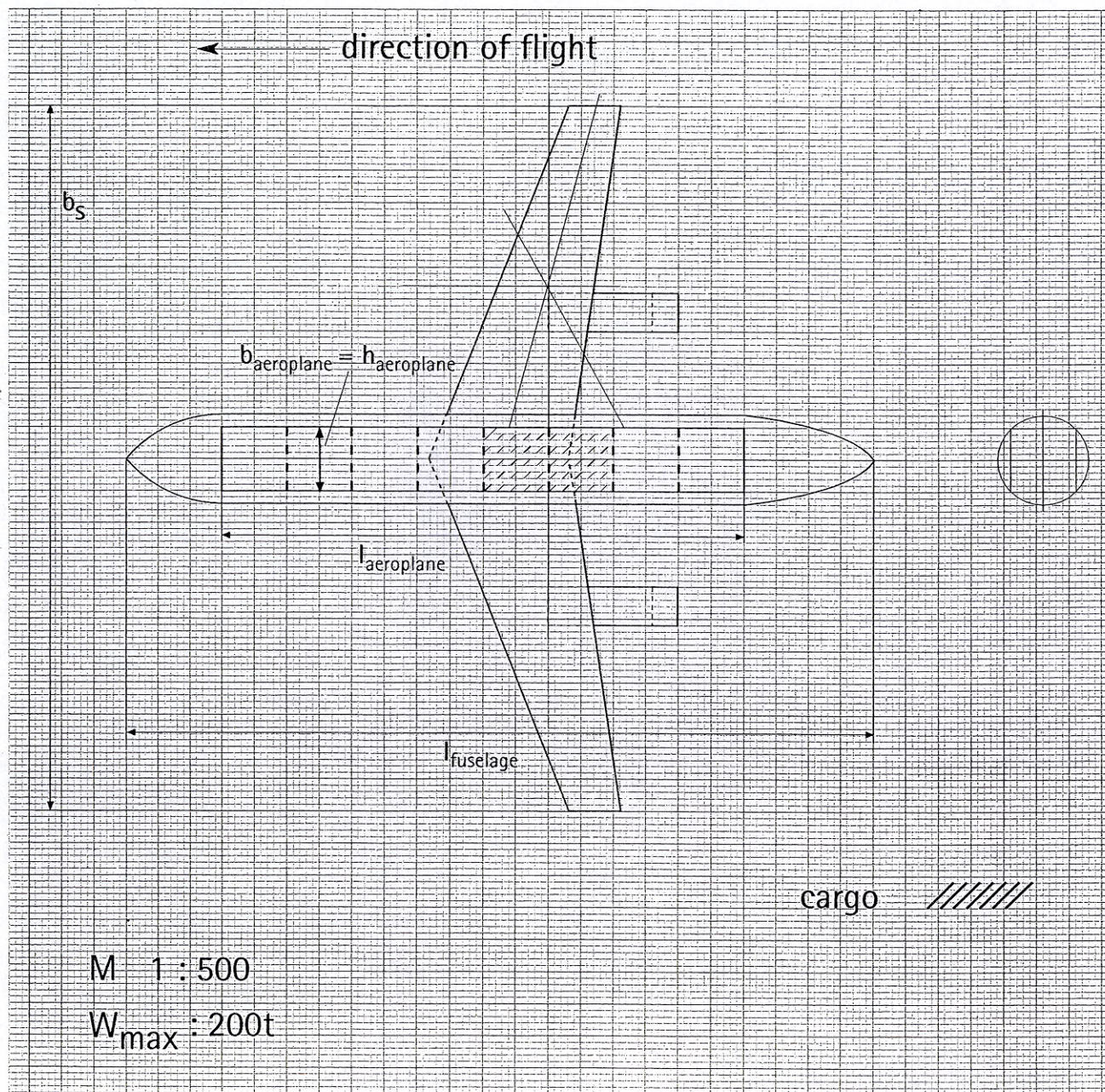
Section 3

Schematic Diagram 4
Transport Aircraft



Section 3

Schematic Diagram 5
Transport Aircraft



Section 4

re. study phase 4

Problem and solution:

Study phase 4 represents a supplement to or extension of study phase 3. Study phase 4 only deals with aeroplane designs of less well known or unknown form.

These are:

- aeroplane with three wings of the same size in tandem arrangement (6)
- aeroplane with wing arrangement in the form of a rhombus (7)
- aeroplane with rear tail and double fuselage (8)
- aeroplane with front tail and double fuselage (9)
- aeroplane with two wings of the same size in tandem arrangement and double fuselage (10)
- aeroplane with front tail and double fuselage, outer fuselages with larger diameter (11)

For the different aeroplane concepts mentioned here, aeroplane configurations can be produced by differently arranging the individual aeroplane components of the initial configuration 1 from section 3 with relation to the aeroplane fuselage and also to each other.

If required by the design, the number of individual aeroplane components is increased or extended by new ones (additional aeroplane elements).

Wing and horizontal tail size of the transport aeroplane designs (6) to (11):

The surfaces for wing and horizontal tail calculated for transport aeroplane design (1) for transport aeroplane configuration 1 are used in aeroplane designs (6) to (11).

Fuselage and engine pod size for transport aeroplane designs (6) to (11):

The values for fuselage length and engine pod size calculated for transport aeroplane design (1) for transport aeroplane configuration 1 are used as initial data in aeroplane designs (6) to (11).

The values for the engine pod size are not altered compared with configuration 1, but the number of engines changes if required by the aeroplane configuration.

Section 4

Results 1

Assumptions for the transport aeroplane designs (6), (7), (8), (9), (10) and (11):

The transport aeroplane configurations 6, 7, 8, 9, 10 and 11 shown on pages 5 to 10 have the same size surface for wing and horizontal tail as configuration 1 in section 3, but the surfaces are sometimes arranged differently to the overall aeroplane hold compared to the basic configurations.

Configuration 6 differs from configuration 4 in section 3 in that a second additional hold element which carries the third wing is inserted in the middle between the existing two wing surfaces of the tandem.

In configuration 6, the aeroplane centre of gravity should be on the connection line of the outer wing surface centres of gravity of the middle wing.

The connection lines of the outer wing surfaces centres of gravity are 2.5 hold elements apart in configuration 6.

Configuration 7 differs from configuration 4 in section 3 in that the main wing, which carries the engines, has a forward sweep, so that the wing ends are brought closer together.

In addition, the overall aeroplane hold between the two wing surfaces is reduced by one hold element compared with configuration 4, so that the distance of the connection lines of the outer wing surfaces centres of gravity is only 3 hold elements here.

The aeroplane centre of gravity in configuration 7 is in the middle between the two wings.

In configuration 8 the wing and horizontal tail surface in relation to the overall aeroplane hold is arranged as in configuration 1 in section 3, but the hold is reduced by two hold elements at the rear.

The horizontal tail lever arm is the same as in configuration 1, so that the horizontal tail surface begins at the end of the fuselage here.

In configuration 8 the horizontal tail is carried by two conical outer fuselages, which begin directly behind the connection line of the outer wing surfaces centres of gravity.

In configuration 8, the aeroplane centre of gravity should lie on the connection line of the outer wing surfaces centres of gravity, as in configuration 1.

Configuration 9 does not differ from configuration 2 in section 3 with regard to the arrangement of the wing and horizontal tail surface to the overall aeroplane hold.

The horizontal tail (front tail) is supported here by two narrow outer fuselages,

Section 4

which begin in front of the connection line of the outer wing surfaces centres of gravity.

In configuration 9 the aeroplane centre of gravity should lie on the connection line of the outer wing surfaces centres of gravity, as in configuration 2.

In configuration 10 there is no difference to configuration 4 in section 3 as regards the arrangement of the wing surfaces to the overall aeroplane hold.

The difference consists in two outer fuselages, which are arranged between the wings, and two additional engines on the front wing.

The outer fuselages begin on the front wing behind the connection line of the outer wing surfaces centres of gravity and end on the corresponding connection line of the rear wing.

In wing span direction, the outer fuselages are the same distance from the overall aeroplane hold as the engines.

In configuration 10 the aeroplane centre of gravity is in the middle between the wing surfaces, as in configuration 4.

In configuration 11 there is no difference to configuration 2 in section 3 as regards the arrangement of the wing and horizontal tail surface to the overall aeroplane hold viewed from above.

The difference consists in two outer fuselages, which carry the horizontal tail (front tail), and which run forwards from the connection line of outer wing surfaces centres of gravity.

In wingspan direction, the outer fuselages are the same distance from the overall aeroplane hold as the engines.

Unlike configuration 2, the horizontal tail (front tail) is not divided and is situated above the overall aeroplane hold.

The aeroplane centre of gravity should lie on the connection line of the outer wing surfaces centres of gravity, as in configuration 2 in section 3.

Section 4

Results 2

Assumptions for the transport aeroplane designs (6), (7), (8), (9), (10) and (11):

The transport aeroplane configurations 7, 9 and 11 shown on pages 6, 8 and 10 have the same length of overall aeroplane hold and fuselage as configuration 1 in section 3.

The transport aeroplane configurations 6, 8 and 10 shown on pages 5, 7 and 9 have a different length of overall aeroplane hold and fuselage compared with configuration 1 in section 3, due to the configuration.

In configurations 6, 7, 8, 9, 10 and 11, the size of an engine pod is the same as that of configuration 1 in section 3.

Configurations 6 and 10 have two additional engines on the front wing due to the higher maximum aeroplane weight.

In configurations 6, 7, 9, 10 and 11 the engines begin on the rear wing or on the wing due to the centre of gravity behind the connection line of the outer wing surfaces centres of gravity.

The engines are only arranged normally in configuration 8 and are in front of the connection line as in configuration 1 in section 3.

In configurations 6 and 10, which each have four engines, the rear engines are arranged above the wing.

This prevents an unwanted mutual influence of the engines.

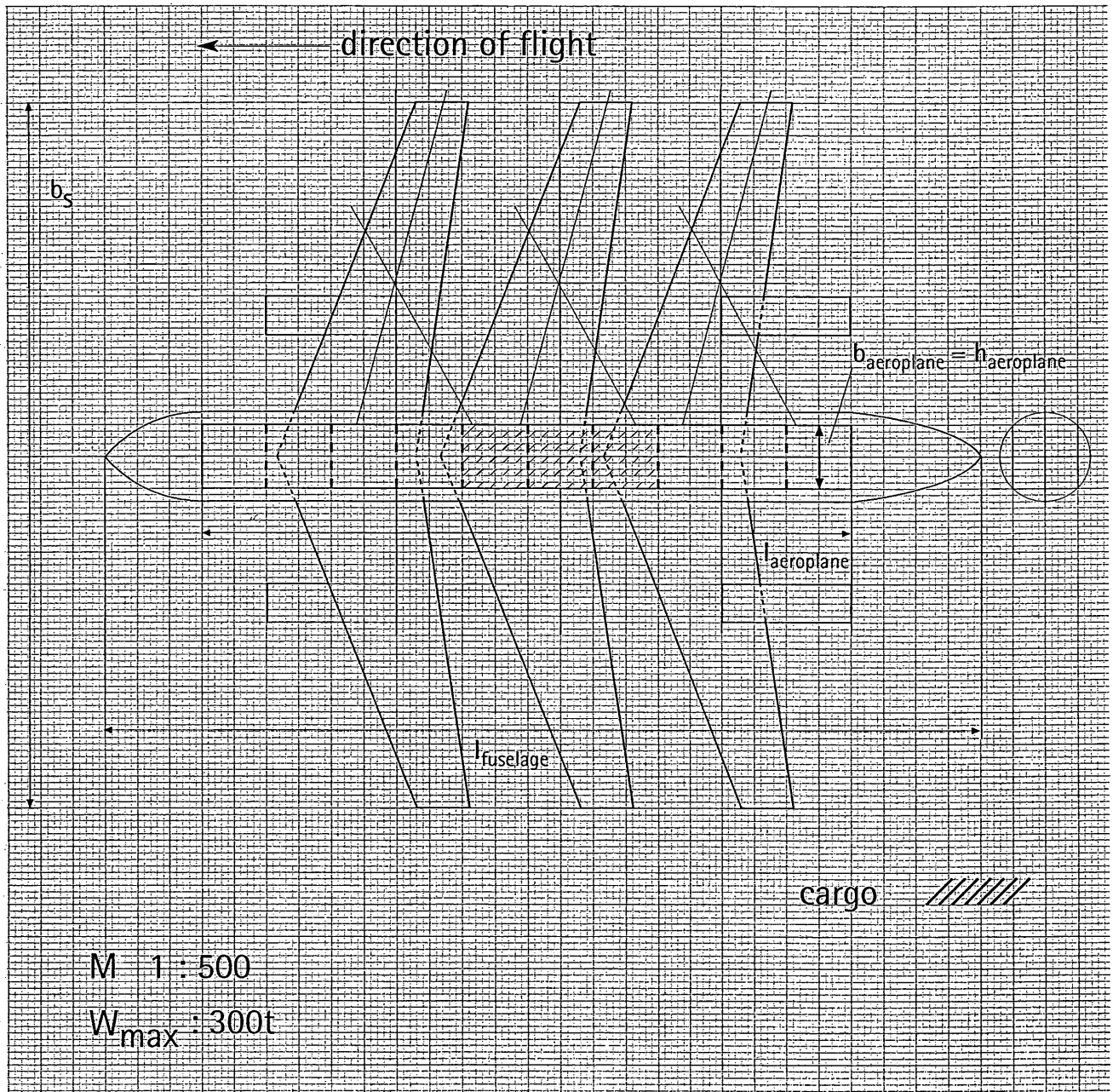
Results 3

For configurations 7, 8, 9, 10 and 11, in addition to the main aeroplane elements, the following additional aeroplane elements are used:

- wing tip elements for configuration 7
- outer fuselage carrier toward rear for configuration 8
- outer fuselage carrier toward front for configuration 9
- outer fuselage carrier between the wings for configuration 10
- outer fuselage carrier toward the front for configuration 11

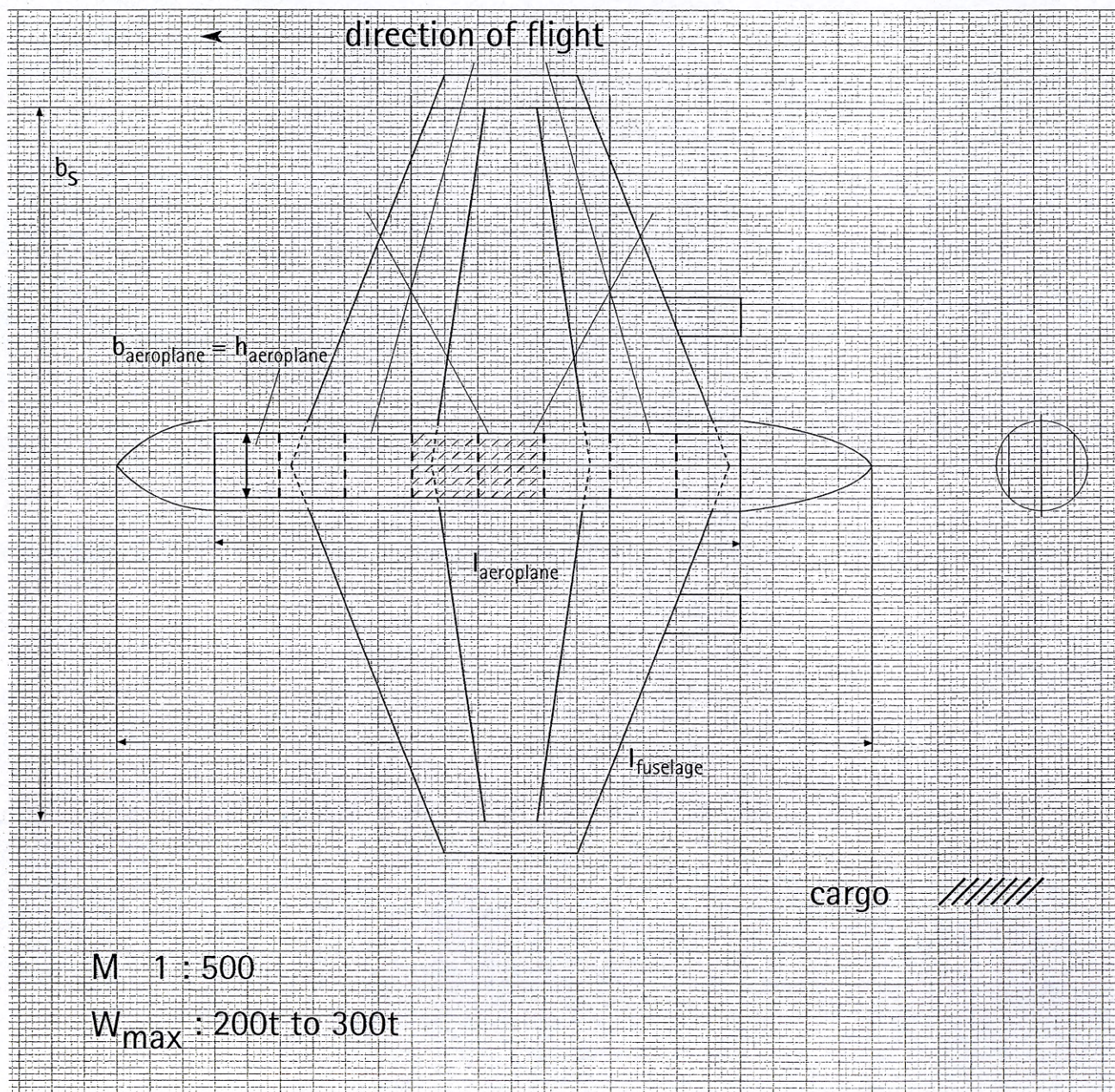
Section 4

Schematic Diagram 6
Transport Aircraft



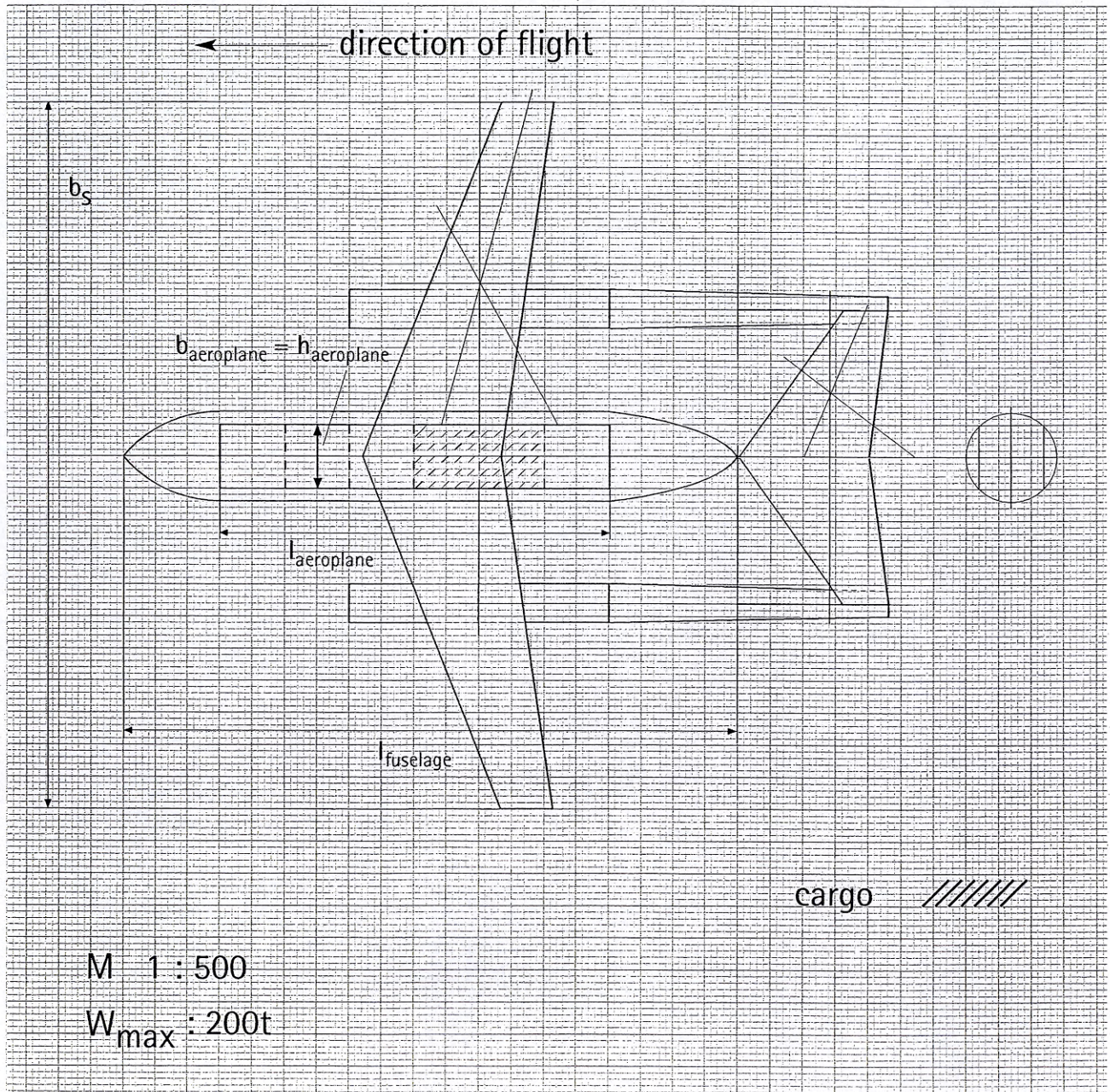
Section 4

Schematic Diagram 7
Transport Aircraft



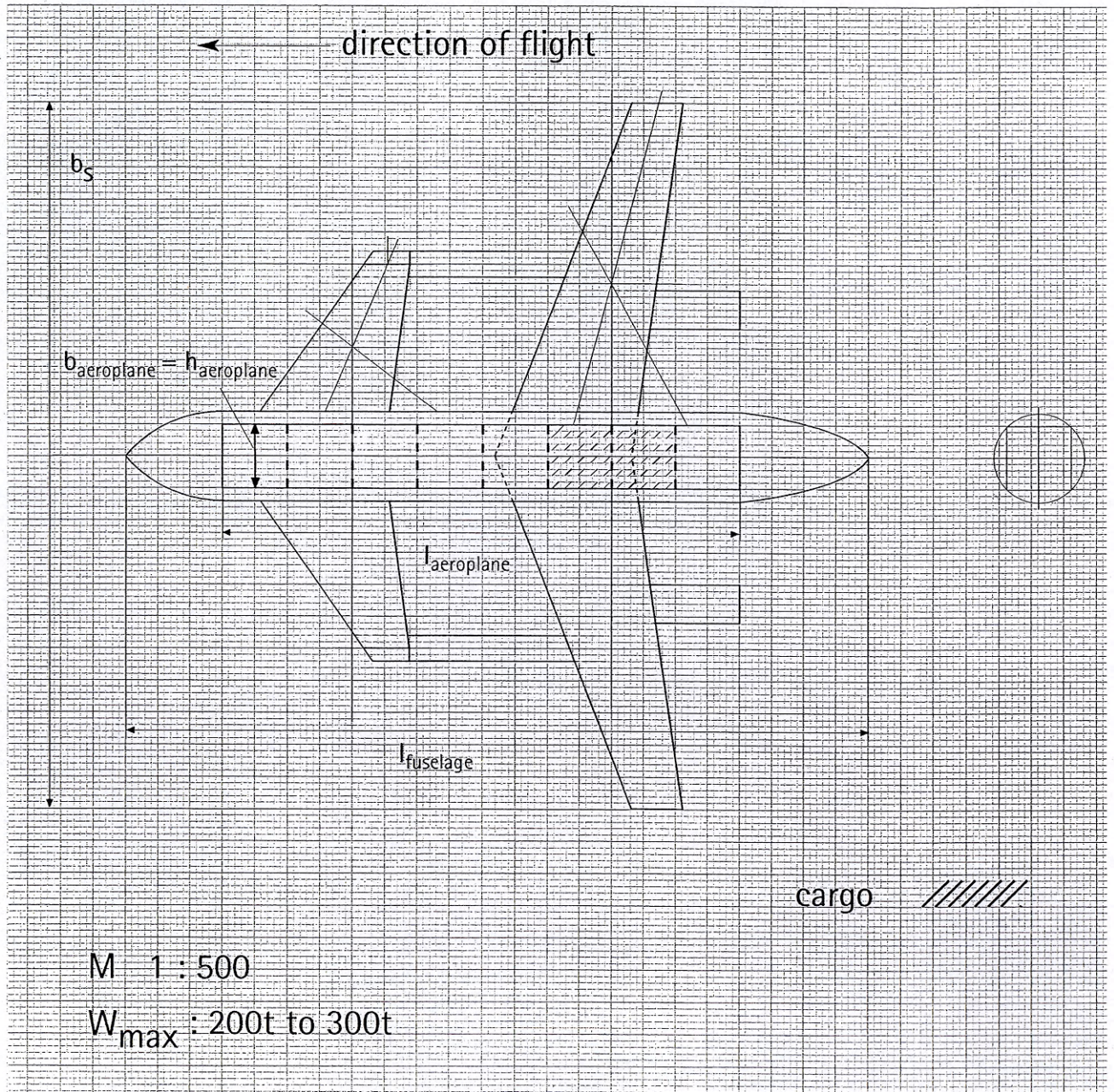
Section 4

Schematic Diagram 8
Transport Aircraft



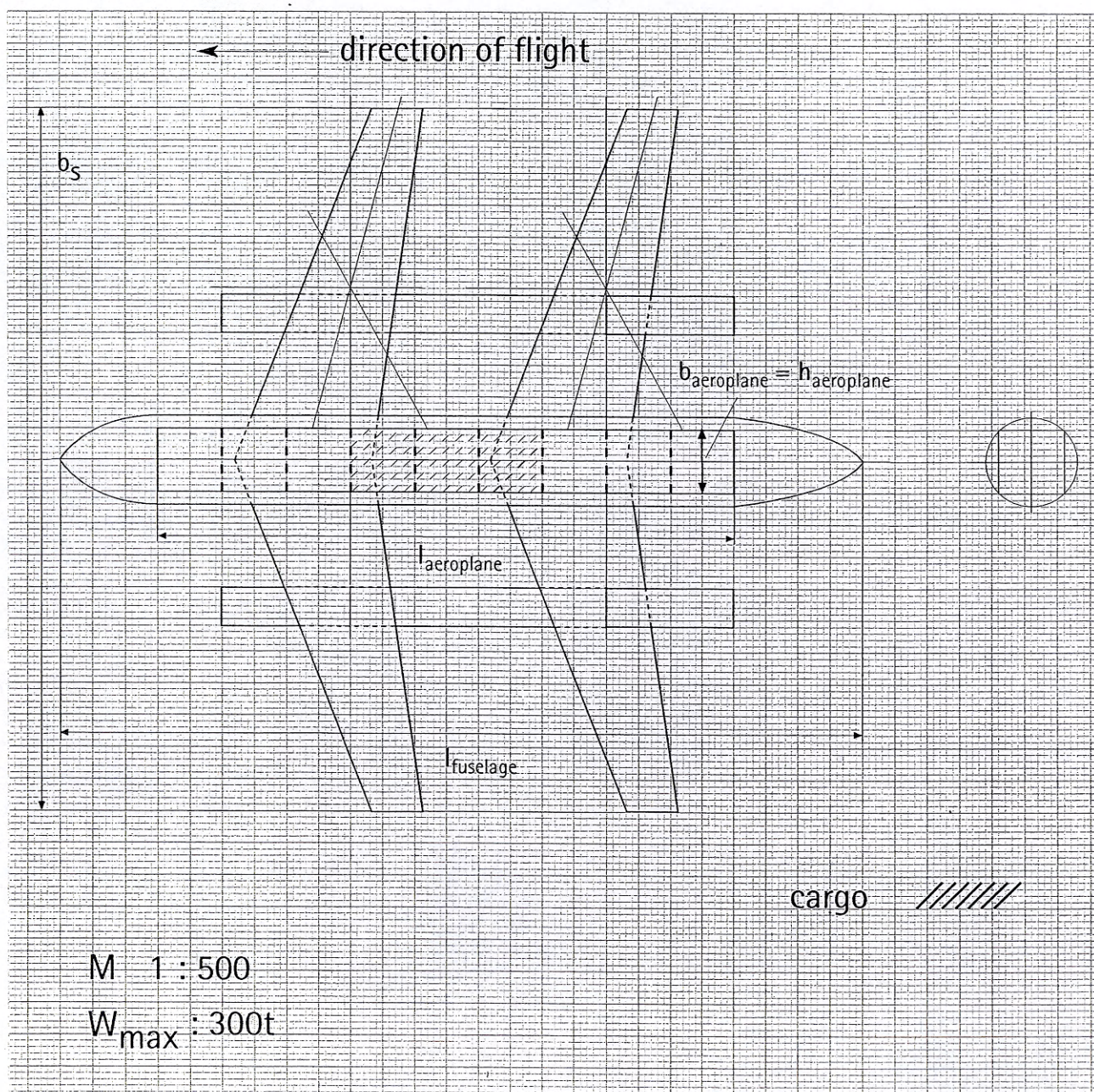
Section 4

Schematic Diagram 9
Transport Aircraft



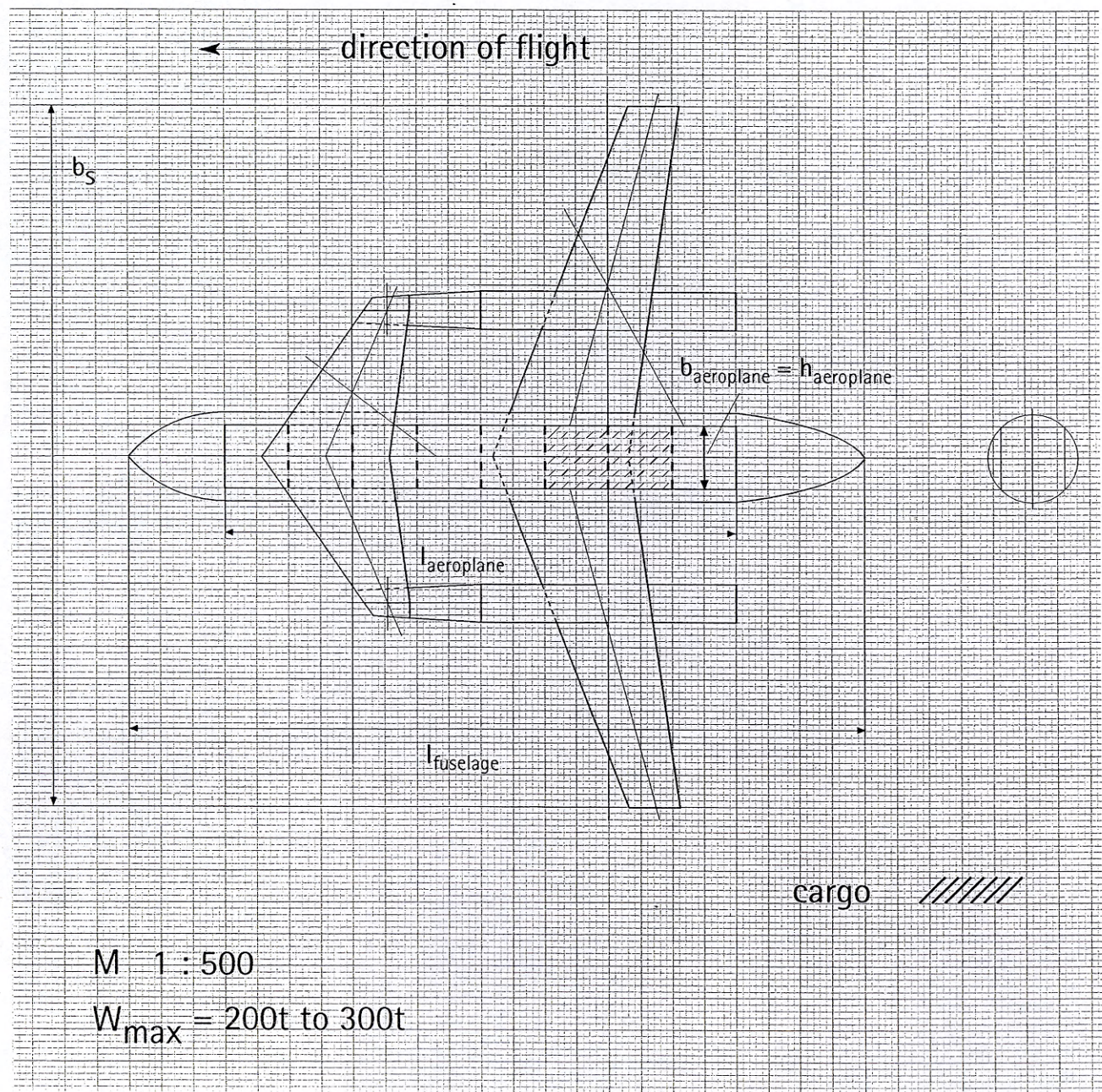
Section 4

Schematic Diagram 10
Transport Aircraft



Section 4

Schematic Diagram 11
Transport Aircraft



Aerodynamic centre, centre of gravity, downwash

Aerodynamic centre, centre of gravity, downwash and interference

Problem and solution:

Position of centre of gravity and elevator unit load

Configurations 1, 2 and 3 of study section 3 and configurations 8, 9 and 11 of study section 4 represent transport aeroplanes with rear or front elevator units of normal size.

Configuration 5 of study section 3 represents a transport aeroplane without the usual elevator unit.

The elevator unit function is to be implemented by vector jets on the engines.

With configurations 1, 2, 3 and 5 of study section 3, as well as with configurations 8, 9 and 11 of study section 4, the centre of gravity of the aeroplane lies by definition on the connecting line of the centres of gravity of the surfaces of the outer wing halves as seen from above.

In a flight with a large positive landing flap deflection, the aerodynamic centre of the outer wing halves also lies approximately on the connecting line of the centres of gravity of the surfaces of the outer wing halves.

The elevator unit therefore does not have to compensate for a wing moment around the lateral axis of the aeroplane and has no upward or downward thrust and therefore no induced resistance either.

With this centre of gravity position, the induced resistance of the complete aeroplane is approximately the same as the induced resistance of the complete wing.

With this centre of gravity position, the elevator unit does not produce any upwash or downwash, which would partly impinge on the wing with configurations 2, 3, 9 and 11.

Even without downwash or upwash of the elevator unit, an inner wing section lies in the wake of the front elevator unit, due to which the zero resistance of the wing is slightly increased.

Position of centre of gravity and wing load

Configuration 4 of study section 3 as well as configurations 7 and 10 of study section 4 represent tandem transport aeroplanes with two wings.

With configuration 4 of study section 3 as well as with configurations 7 and 10 of study section 4, the centre of gravity position in the centre of the distance of the connecting lines of the surface centres of gravity of the outer wing halves is defined in the view from above.

Aerodynamic centre, centre of gravity, downwash

Configuration 6 of study section 4 represents a tandem transport aeroplane with three wings.

Here the centre of gravity should be on the connecting line of the surface centres of gravity of the outer wing halves of the middle wing in the view from above.

In a flight with a large positive landing flap deflection, the aerodynamic centre of all outer wing halves corresponds approximately to the defined centre of gravity positions in the tandem configurations.

Therefore, no wing moment has to be compensated for around the lateral axis of the aeroplane.

As with tandem aeroplanes the leading wing produces a downwash, the trailing wing must compensate for this with a slightly positive landing flap deflection, if the basic setting of the wings to the fuselage is the same.

The trailing wing therefore has a greater positive landing flap deflection than the leading wing.

With the tandem configurations, the trailing wing lies completely in the wake of the leading wing, which slightly increases the zero resistance of the complete wing.

Note on the centre of gravity positions:

The configurations shown in study sections 3 and 4 have a defined centre of gravity position such that a fully electric control system is required for longitudinal and lateral stabilisation for all configurations except configuration 1.

Results:

For configuration 1 of study section 3, the wing downwash on the elevator unit was calculated for a normal flight.

The calculation was based on the following data:

$$C_L = 0.6$$

$$z_{ss} = 0 \text{ (high position of the elevator unit)}$$

If the elevator unit is arranged at wing height, the downwash $\varepsilon = 2.7^\circ$ is produced at the location of the elevator unit.

The associated induced angle of attack of the wing is $\alpha_i = 1.4^\circ$.

An elevator unit arranged on the side elevator unit in a T-shape elevator unit is not affected by the wing downwash.

Section 5

re. study phase 5

Problem and solution:

In study phases 1 to 4, a new design method was presented with the aid of which configurations for large passenger and transport aircraft can be designed.

The advantage of applying this method is that it produces realistic configurations which are based on established basic assumptions.

This design method also enables a large number of different configurations to be developed and exactly compared with each other.

In study phases 3 and 4, the new method was used to create 11 transport aircraft configurations, which are useful according to current knowledge.

The initial data (basic assumptions) of the individual configurations are designed so that they can be used again directly for more exact flying performance or flying characteristic calculations.

As the new method works with the definition of an overall aircraft volume, it is also possible to scale all initial configurations and examine any aircraft size.

In order to be able to design transport aircraft configurations with the method according to study phases 1 to 4, the following work blocks are required:

Block 1, with the formulae for calculation of the parameters for configuration 1
(see summary of sections 1, 2 and 3, solution)

Block 2, with input data for the formulae of block 1
(see summary of sections 1, 2 and 3, results)

Block 3, with results from the formulae of block 1
(see summary of sections 1, 2 and 3, results)

Block 4, to design the various configurations

Block 5, for performance calculation of the designed configurations

Block 6, for scaling the designed configurations

Block 7, for important results of the scaled configurations

It is useful to explain the new design method with a flow chart, see pages 3 to 7.

Section 5

Results:

A flow chart of the new design method is shown on pages 3 to 7.

The columns of the flow chart correspond to the seven work blocks described on page 1.

- 1: Mathematical equations
- 2: Existing aircraft, input data
- 3: New aircraft, result data
- 4: New aircraft/configurations
- 5: Differences compared to new basic aircraft
- 6: Scaling of the various aircraft
- 7: Weight categories, requirements
Results: cargo compartment, performances

Weight categories, requirements
Results: mass moments of inertia, properties

The equations in block 1 depend on block 2 or on the associated input data.

The results of block 1 influence block 3.

The superordinate requirements influence block 2 and are in turn influenced by block 3.

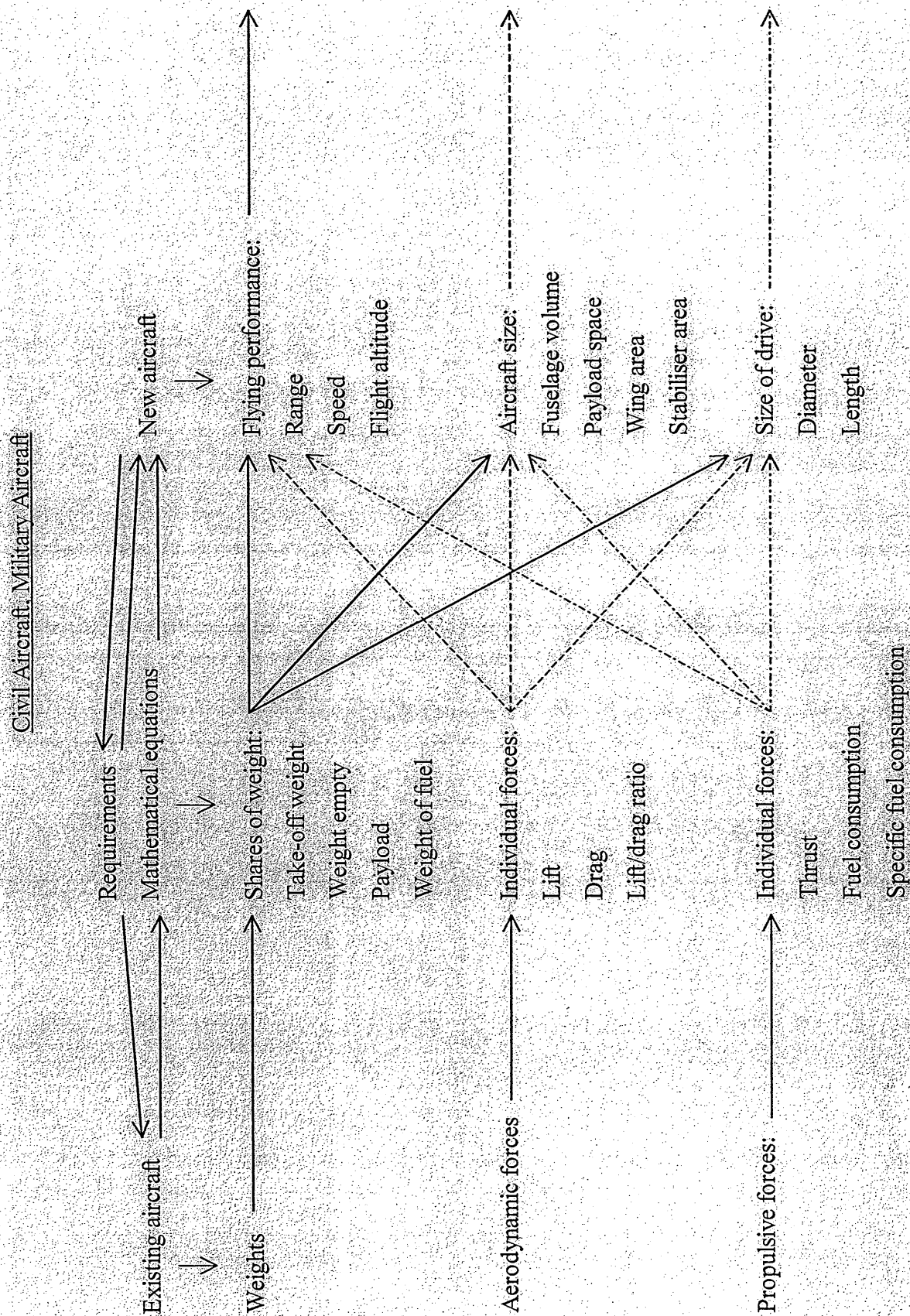
The requirements will be:

Aircraft data such as maximum aircraft weight, cargo compartment size and specific gravity of the cargo

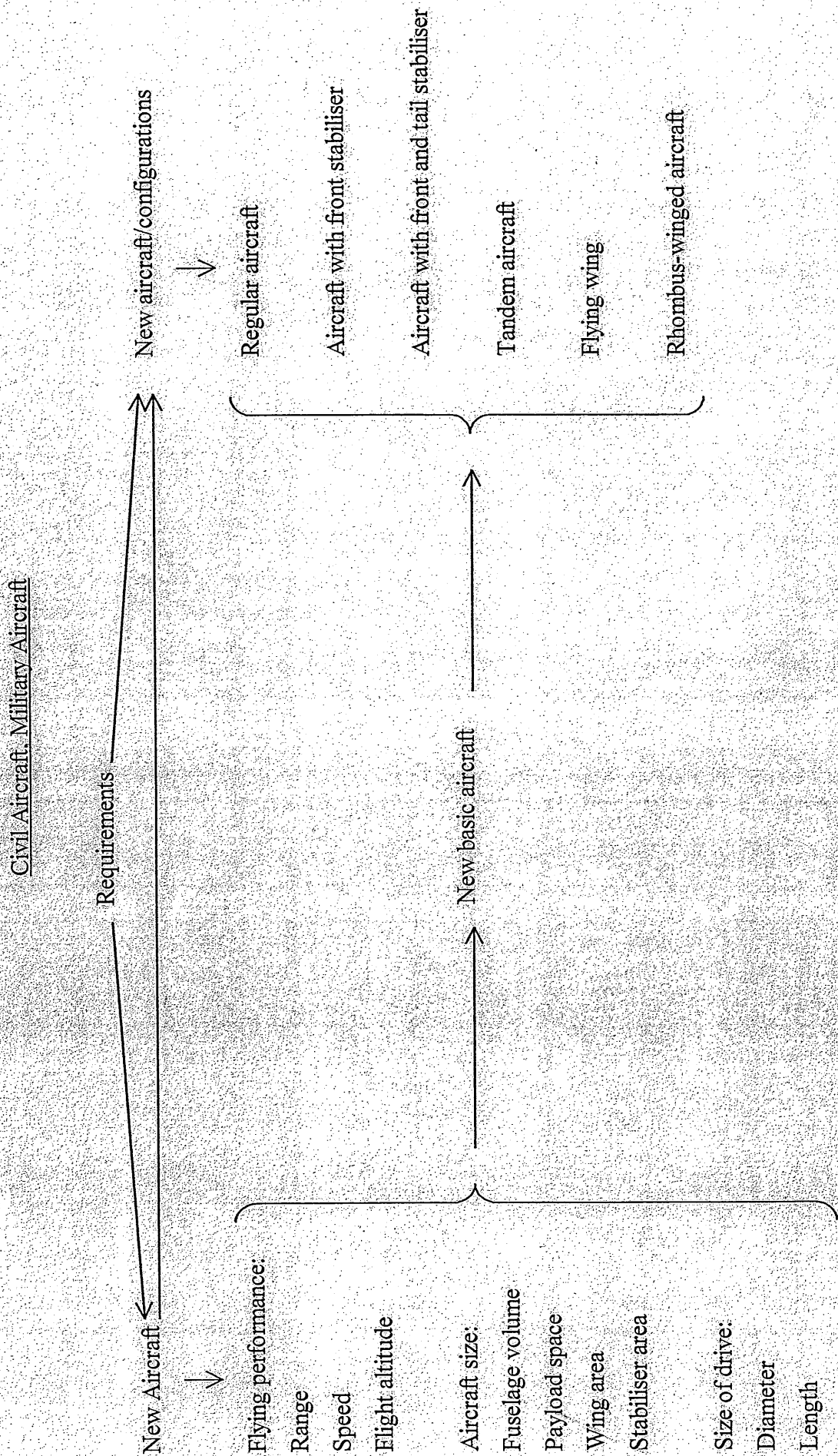
Flying performance data such as range, flying speed and flying altitude

Flying characteristic data such as accelerations in the direction of the longitudinal, lateral and vertical axes of the aircraft

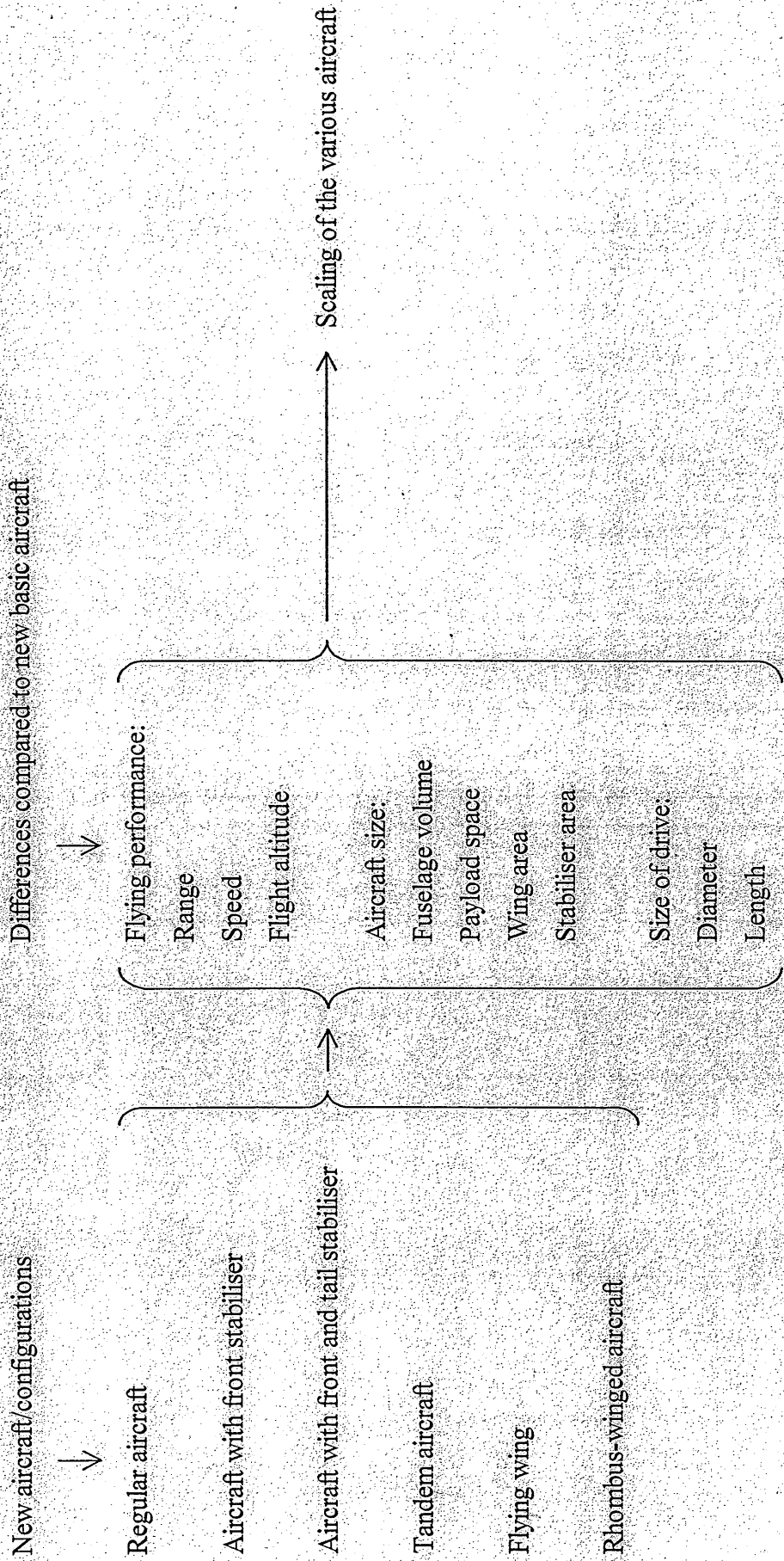
Flying characteristic data such as angular accelerations around the longitudinal, lateral and vertical axes of the aircraft



Section 5



Civil Aircraft, Military Aircraft



Section 5

Civil Aircraft, Military Aircraft

Weight categories, e.g.:	Requirements, e.g.:	Cargo compartment, e.g.:	Performance
200 t	Performance: Range Speed Flight altitude	250 m³	Range Speed Flight altitude
300 t		375 m³	
400 t	Payload: Seating compartment Cargo compartment	500 m³	Payload
500 t		625 m³	Type of payload

Specific gravity of the cargo: 0.2 t/m³

Section 5

Civil Aircraft, Military Aircraft

Weight categories, e.g.:	Requirements, e.g.:	Mass moments of inertia	Qualities
200 t	Overall aircraft:	Overall aircraft:	Overall aircraft:
300 t	Qualities	Moments of inertia	Longitudinal motion
400 t	Longitudinal motion	I_y	Lateral motion
	Lateral motion	I_z	Rolling motion
	Rolling motion	I_x	
500 t	Payload:	Payload:	Payload:
	Accelerations	Masses	Longitudinal acceleration
	Longitudinal acceleration	m_x	Lateral acceleration
	Lateral acceleration	m_y	Vertical acceleration
	Vertical acceleration	m_z	

Indices x, y, z: related to the axes x, y, z of the overall aircraft

re. study phase 6

Problem and solution:

To determine the flight performances of large passenger or transport aircraft more exactly, the so-called aircraft polars of the relevant aircraft are required.

It is useful to develop formulae for a variable polar which can be adapted to any aircraft configuration.

For a square aircraft polar without and with wing flap deflection, the following formulae can be used:

$$C_D = C_{D0} + k \cdot C_L^2 \quad (\text{without flap deflection}) \quad (31)$$

$$C_L = (dC_L/d\alpha)_S \cdot \alpha_S \quad (32)$$

$$C_{D, \text{flap}} = C_{D0} + \Delta C_{D, \text{flap}} + k \cdot (C_{L, \text{flap}} - \Delta C_{L, \text{flap}})^2 \quad (\text{with flap deflection}) \quad (33)$$

$$C_{L, \text{flap}} = C_L + \Delta C_{L, \text{flap}} \quad (34)$$

Formula (31) applies to a square polar which is symmetrical to the C_D axis.

Formula (33) applies to a square polar which is asymmetrical to the C_D axis or depending on the algebraic sign of $\Delta C_{L, \text{flap}}$ is offset in C_L direction by $\Delta C_{L, \text{flap}}$.

In formulae (31) to (34), the parameters C_{D0} , k for a certain aircraft or a given aircraft configuration and the parameters $\Delta C_{L, \text{flap}}$ and $\Delta C_{D, \text{flap}}$ with wing flap deflection are constant.

If it is to be made clear that the square aircraft polar applies without and with wing flap deflection for different aeroplanes or configurations, i.e. that it is variable, this is written as follows:

$$C_{D0} = C_{D0, \text{aeroplane}} \quad (35)$$

$$k = k_{\text{aeroplane}} \quad (36)$$

$$(dC_L/d\alpha)_S = (dC_L/d\alpha)_{S, \text{aeroplane}} \quad (37)$$

$$\Delta C_{L, \text{flap}} = \Delta C_{L, \text{flap}, \text{aeroplane}} \quad (38)$$

$$\Delta C_{D, \text{flap}} = \Delta C_{D, \text{flap}, \text{aeroplane}} \quad (39)$$

Section 6

Results:

The square aircraft polar was calculated without and with wing flap deflection with the associated curves $C_L = f(\alpha_s)$ and $C_{L, \text{flap}} = f(\alpha_s)$ for configuration 1 from section 3, see pages 3 to 7.

This was based on the following data:

$$C_{D0} = 0.015$$

$$k = 0.0415$$

$$(dC_L/d\alpha)_s = 5.0$$

$$\Delta C_{L, \text{flap}} = -0.3; \quad \Delta C_{L, \text{flap}} = 1.235$$

$$\Delta C_{D, \text{flap}} = 0.0022; \quad \Delta C_{D, \text{flap}} = 0.0079$$

$$\eta = -14^\circ; \quad \eta = +60^\circ \text{ (maximum flap deflection)}$$

The square aircraft polar without wing flap deflection has three especially important points for flight performances calculations:

1. Point for the best aircraft glide coefficients $(C_D/C_L)_{\min}$
2. Point for the lowest aircraft sinking speed $(C_D^2/C_L^3)_{\min}$
(also point for best climb)
3. Point for largest aircraft range $(C_D^2/C_L)_{\min}$

With these polar points:

$$1. C_L = (C_{D0}/k)^{1/2}; \quad C_D = 2 \cdot C_{D0}$$

$$2. C_L = (3 \cdot C_{D0}/k)^{1/2}; \quad C_D = 4 \cdot C_{D0}$$

$$3. C_L = (C_{D0}/(3 \cdot k))^{1/2}; \quad C_D = (4/3) \cdot C_{D0}$$

This produces the following reciprocal glide coefficients:

$$1. C_D/C_L = 2 \cdot (C_{D0} \cdot k)^{1/2}$$

$$2. C_D/C_L = (4/3)^{1/2} \cdot 2 \cdot (C_{D0} \cdot k)^{1/2}$$

$$3. C_D/C_L = (4/3)^{1/2} \cdot 2 \cdot (C_{D0} \cdot k)^{1/2}$$

With configuration 1, these reciprocal glide coefficients result in:

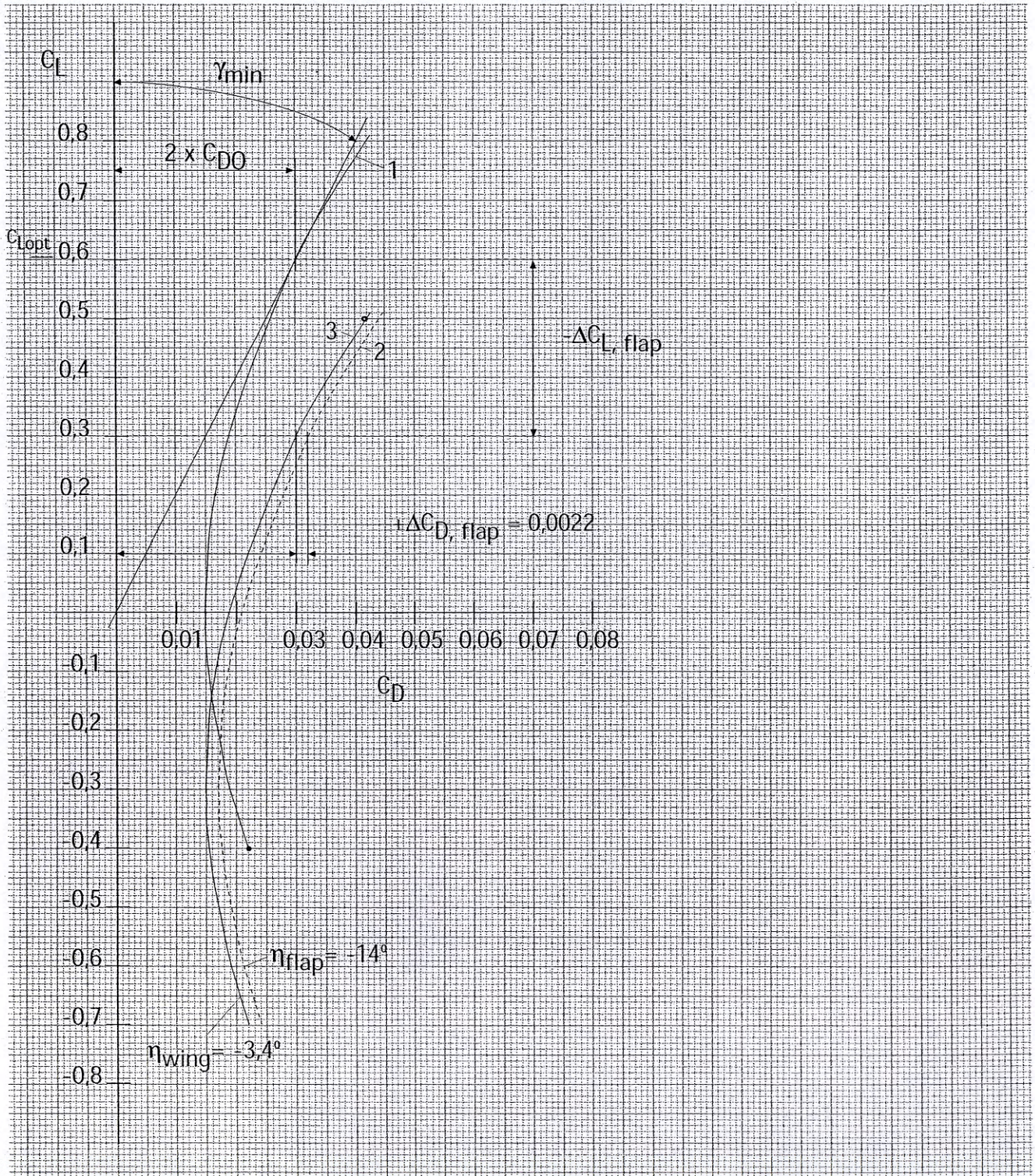
$$1. C_D/C_L = 0.05$$

$$2. C_D/C_L = 0.0577$$

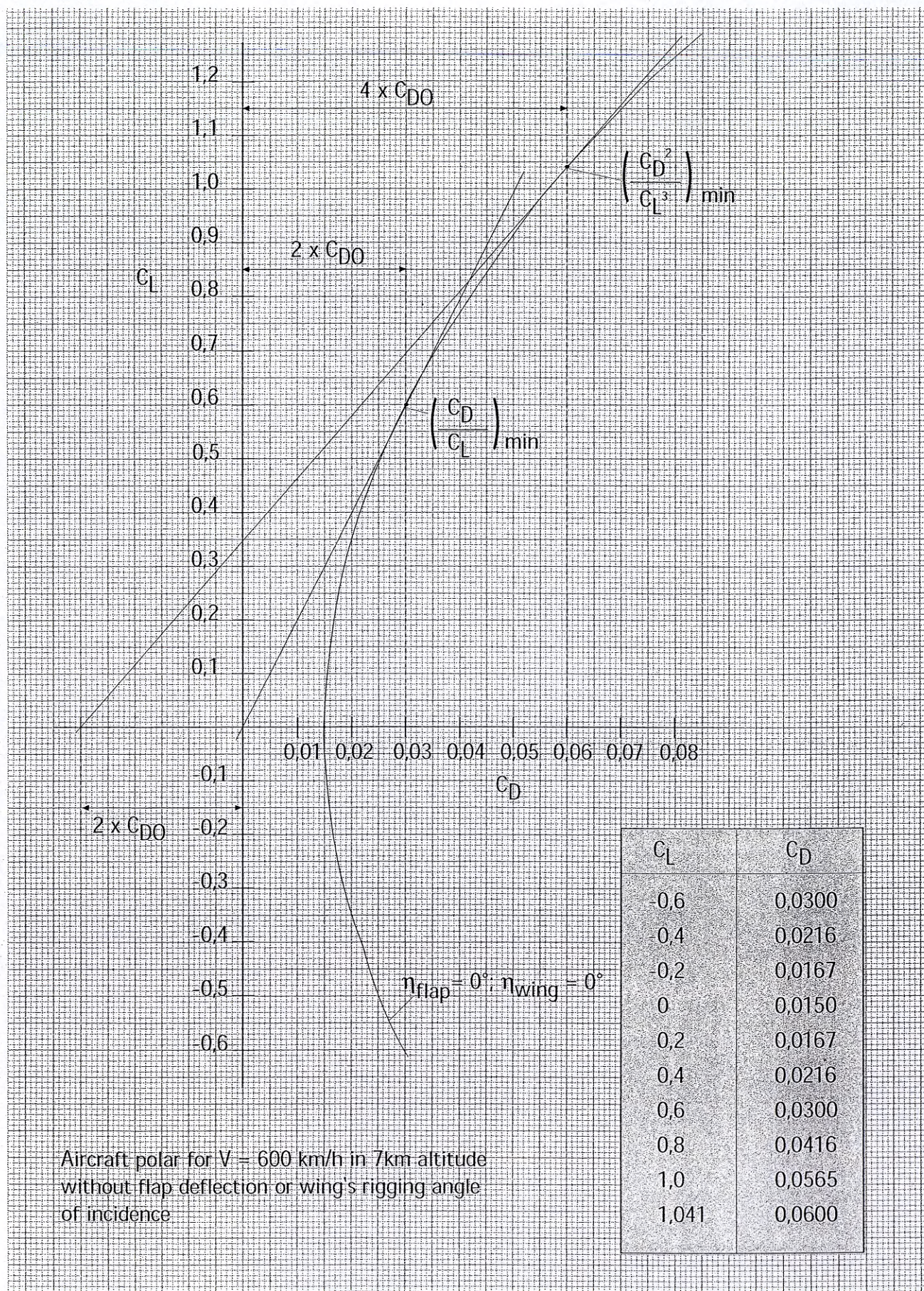
$$3. C_D/C_L = 0.0577$$

Section 6

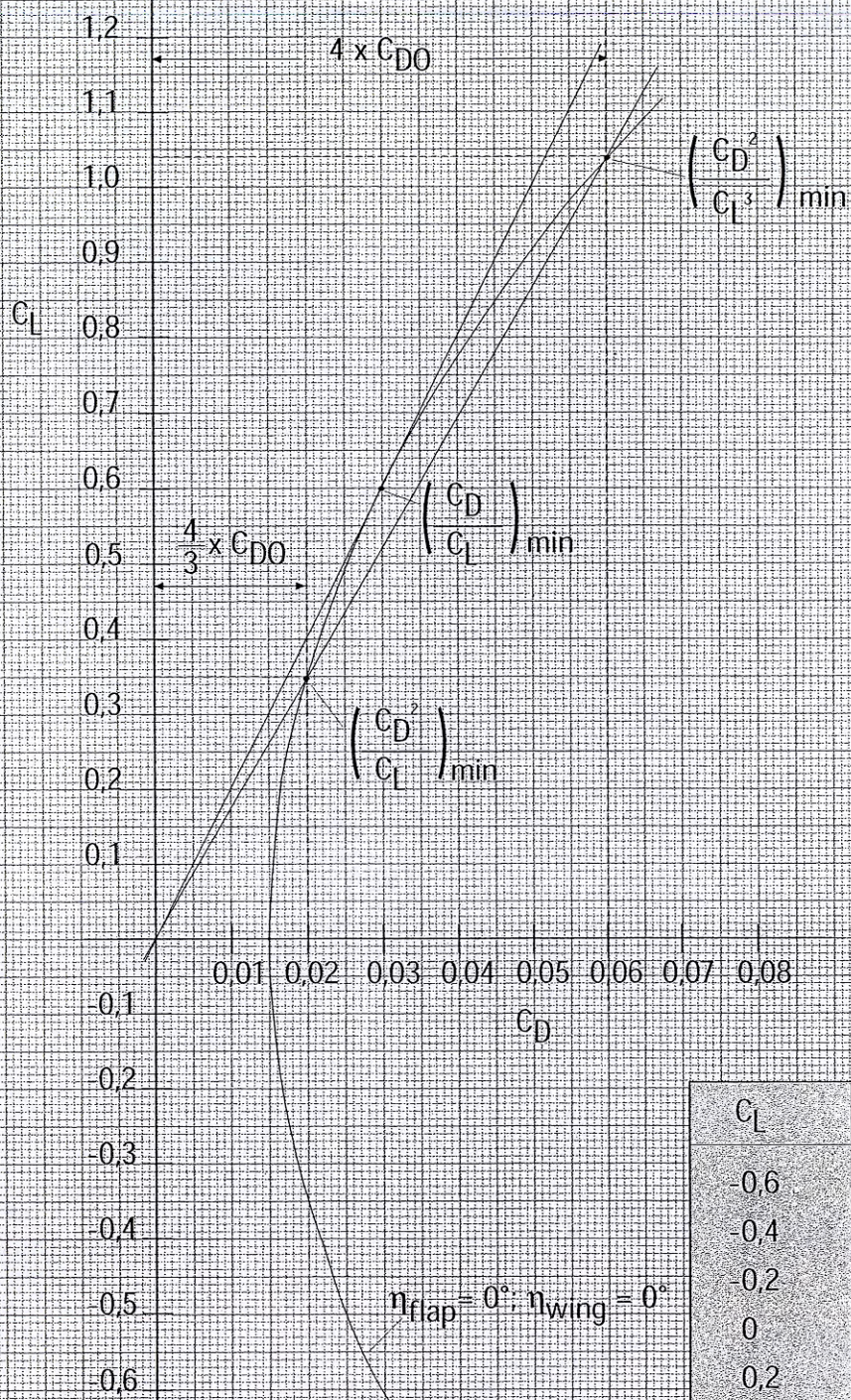
Aircraft polar for $V = 600 \text{ km/h}$ in 7 km altitude
without (1) and with (2) flap deflection
or with wing's rigging angle of incidence (3)



Section 6



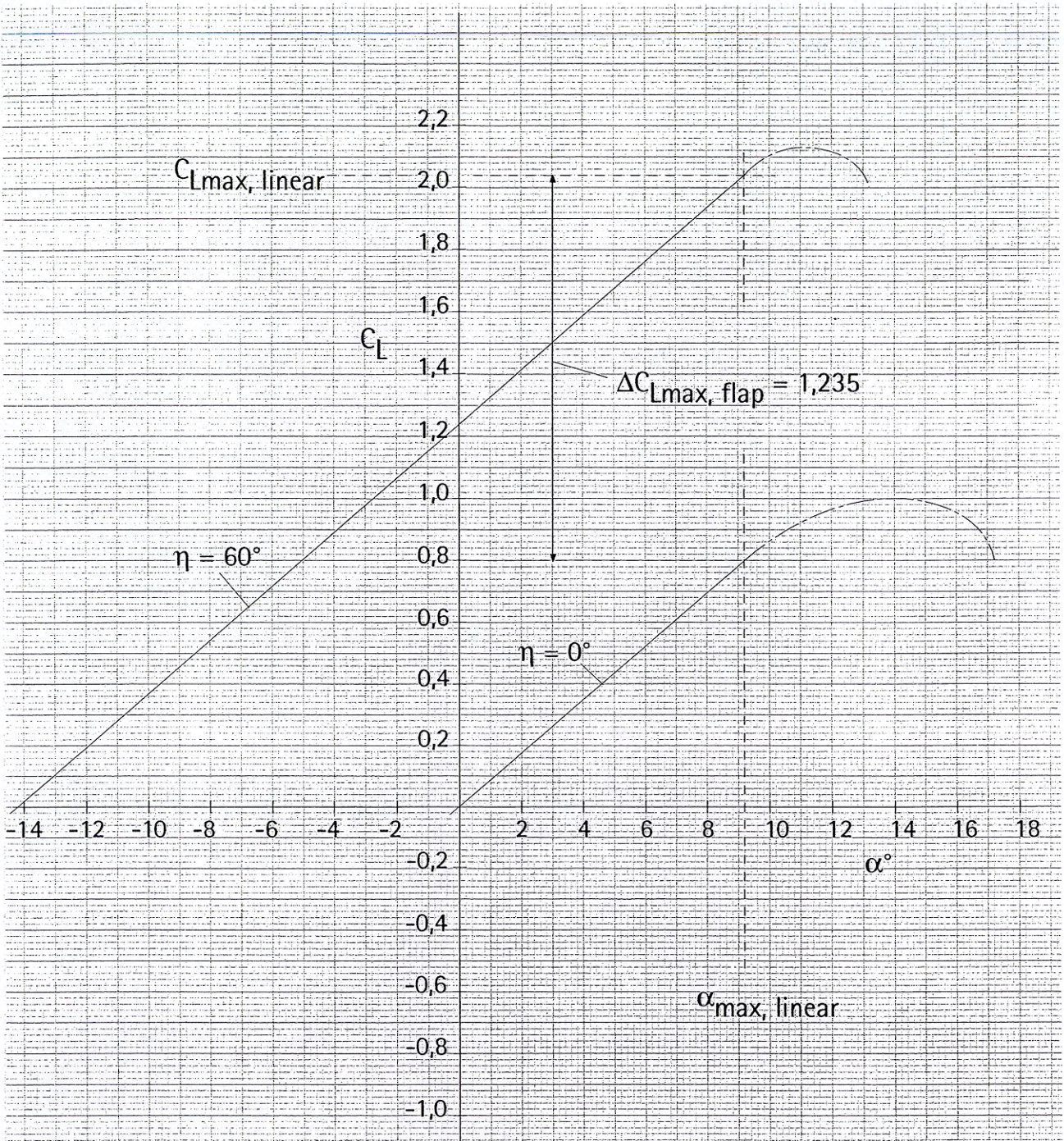
Section 6



Aircraft polar for $V = 600$ km/h in 7km altitude without flap deflection or wing's rigging angle of incidence

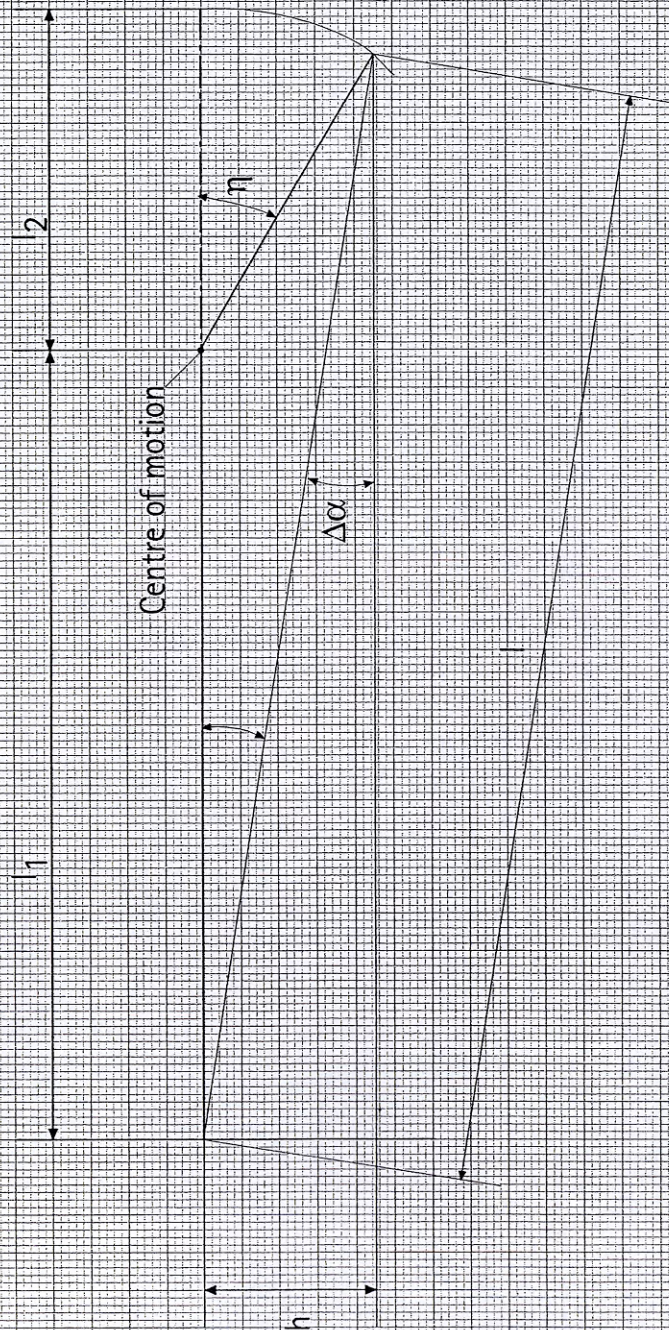
C_L	C_D
-0.6	0,0300
-0.4	0,0216
-0.2	0,0167
0	0,0150
0,2	0,0167
0,4	0,0216
0,6	0,0300
0,8	0,0416
1,0	0,0565
1,041	0,0600

Section 6



Influence of the wing flap deflection on C_L

Section 6



Angle of attack $\Delta\alpha$ due to flap deflection η

Section 7

re. Study phase 7

Problem and solution:

In order to create a full design of a large passenger or transport aircraft, the engine size and the engine type must be known in addition to the dimensions for the fuselage, wings and stabiliser.

For large transport aircraft, four engine types can be considered, namely:

1. Propeller piston engines (referred to here as PPE)
2. Turboprop jet engines (PTJ or turboprops)
3. Turbofan engines (TF or turbofans)
4. Turbojet engines (TJ or turbojets)

The individual engine types have different specific fuel consumption, which increases from point 1 to point 4.

PPE engines $0.23 \text{ kg}/(\text{PS} \cdot \text{h})$

PTJ engines $0.25 \text{ kg}/(\text{PS} \cdot \text{h})$

TF engines $0.5 \text{ to } 0.9 \text{ kg}/(\text{kp} \cdot \text{h})$

TJ engines $1.0 \text{ kg}/(\text{kp} \cdot \text{h})$

Schematic diagrams of these engine types are shown on pages 5 and 6.

For higher speeds ($V \geq 600 \text{ kph}$), engine types 2, 3 and 4 are suitable.

With the same net thrust, the four engine types have different outer dimensions.

Empirical formulae can be developed with the aid of which the engine parameter l/d_f can be calculated for the individual engine types.

If the engine diameter d_f is known, the length of the engine can be determined via the engine parameter l/d_f .

To obtain the engine diameter, the size of the net thrust must be given or assumed.

Section 7

In study 7 it was shown that the creation of the following diagrams is essential:

- a) Engine main flow ratio = f (engine outer dimension ratio), empirical diagram
- b) Engine main flow ratio = f (engine bypass ratio)
- c) Engine main flow ratio = f (engine speed ratio,
engine bypass ratio)

It is also useful to make a comparison of outer dimensions for a basic engine.

The outer dimensions of an engine change if other external and internal operating conditions are given.

Diagram a) is produced by plotting relevant data of potential engines.

To produce diagrams b) and c), mathematical or physical formulae are developed.

For a given engine main flow ratio A_1/A_1 , the associated engine outer dimension ratio can be read off in diagram a).

For a given engine bypass ratio A_2/A_1 , the associated engine main flow ratio can be read off in diagram b).

Diagram c) shows how the engine main flow ratio A_1/A_1 depends on the engine speed ratio V/V_2 with different engine bypass ratio A_2/A_1 .

Diagrams a), b) and c) and the outer dimension comparison are shown on pages 7 to 10.

For the outer dimension comparison, a turbojet with an $l/d_f = 3$ was assumed as the basic engine.

To obtain the outer dimension ratios l/d_f shown on page 10 for the basic engine, the size of the engine parameters V_2/V_1 , A_2/A_1 and a_1/a_2 must be varied accordingly.

In case 1.) of the outer dimension comparison, the thrust that one engine can generate is produced by two engines.

In cases 2.) and 3.) of the outer dimension comparison, only one engine generates all the thrust.

Section 7

Formulae for diagram a)

Calculation of the ratio of length/diameter of the engine pods:

$$(l/d_I)_{\text{Turbofan}} = (l/d_I)_{\text{Turboprop}} + (A_1/A_I) \cdot \Delta(l/d_I)_{\text{Turbojet}} \quad (40)$$

$$(l/d_I)_{\text{Turboprop}} = 2.1 \cdot (l/d_I)_{\text{Prop piston engine}} \quad (41)$$

$$(l/d_I)_{\text{Prop piston engine}} = 1.0 \quad (42)$$

$$\Delta(l/d_I)_{\text{Turbojet}} = 0.8 \quad (43)$$

$$(A_1/A_I)_{\text{Turbofan}} = 0 \text{ to } 1.0 \quad (44)$$

$$(A_1/A_I)_{\text{Turbojet}} = 1.0 \quad (45)$$

$$(l/d_I)_{\text{Turbojet}} = (l/d_I)_{\text{Turboprop}} + \Delta(l/d_I)_{\text{Turbojet}} \quad (46)$$

Calculation of the engine pod diameter and engine pod length:

$$d_I = (4 \cdot A_I / \pi)^{1/2} \quad (47)$$

$$A_I = (C_D/C_L) \cdot W_{\max} / (\rho \cdot V_{\text{opt}}^2) \quad (48)$$

$$F_{(\text{level})} = (C_D/C_L) \cdot W_{\max} \quad (49)$$

$$l = (l/d_I) \cdot d_I \quad (50)$$

Formulae for diagrams b) and c)

$$\text{b) } A_1/A_I = 1/(1 + A_2/A_I) \quad (51)$$

$$\text{c) } A_1/A_I = (k - 1)/(A_2/A_I - 1) \quad (52)$$

$$k = V/V_2 \quad (53)$$

Formulae for the outer dimension comparison

$$l_2/l_1 = (V_2/V_1)^2 \cdot (a_1/a_2) \quad (54)$$

$$d_{I2}/d_{I1} = (A_{I2}/A_{I1})^{1/2} \quad (55)$$

$$l_2/d_{I2} = (V_2/V_1)^2 / (A_{I2}/A_{I1})^{1/2} \cdot (a_1/a_2) \cdot (l_1/d_{I1}) \quad (56)$$

Section 7

Results:

The parameter (l/d_i) as well as the engine diameter d_i and the engine length l were calculated for engine types 1, 2 3 and 4 with configuration 1 shown on page 6, section 3.

This was based on the following data:

$$(A_1/A_i)_{\text{Turbojet}} = 1.0$$

$$(A_1/A_i)_{\text{Turbofan}} = 0.143$$

$$(A_1/A_i)_{\text{Turboprop}} = 0$$

$$(A_1/A_i)_{\text{Prop piston engine}} = 0$$

$$C_D/C_L = 0.05 \text{ (minimum value)}$$

$$W_{\max} = 200 \text{ t}$$

$$V_{\text{opt}} = 600 \text{ km/h} = 166.67 \text{ m/s (flying height 7 km)}$$

$$(l/d_i)_{\text{Turbojet}} = 2.9$$

$$d_{i, \text{Turbojet}} = 2.8 \text{ m}$$

$$l_{\text{Turbojet}} = 8.12 \text{ m}$$

$$(l/d_i)_{\text{Turbofan}} = 2.21$$

$$d_{i, \text{Turbofan}} = 2.8 \text{ m}$$

$$l_{\text{Turbofan}} = 6.2 \text{ m}$$

$$(l/d_i)_{\text{Turboprop}} = 2.1$$

$$d_{i, \text{Turboprop}} = 2.8 \text{ m}$$

$$l_{\text{Turboprop}} = 5.88 \text{ m}$$

$$(l/d_i)_{\text{Prop piston engine}} = 1.0$$

$$d_{i, \text{Prop piston engine}} = 2.8 \text{ m}$$

$$l_{\text{Prop piston engine}} = 2.8 \text{ m}$$

$$(l/d_i)_{\text{Prop piston engine}}$$

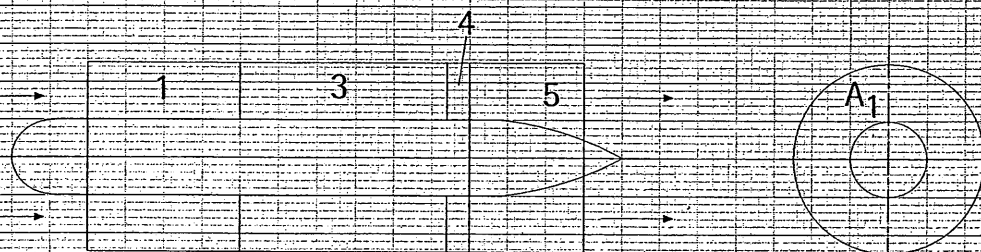
$$(l/d_i)_{\text{Turboprop}} = (l/d)_{\text{Turboprop}}$$

$$(l/d_i)_{\text{Prop piston engine}} = (l/d)_{\text{Prop piston engine}}$$

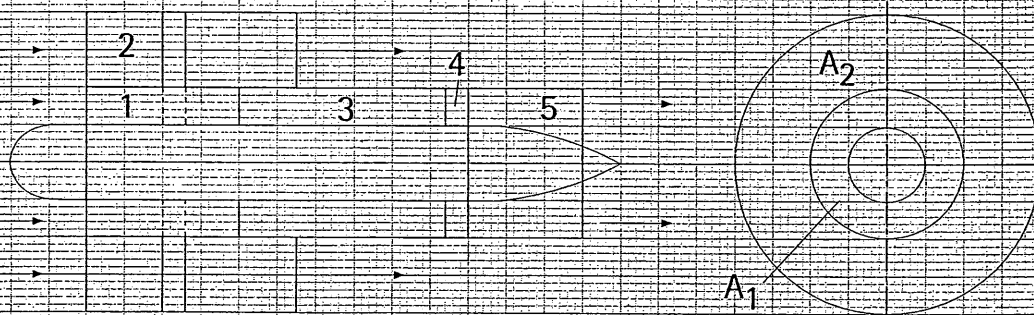
Section 7

Schematic diagrams of various engines

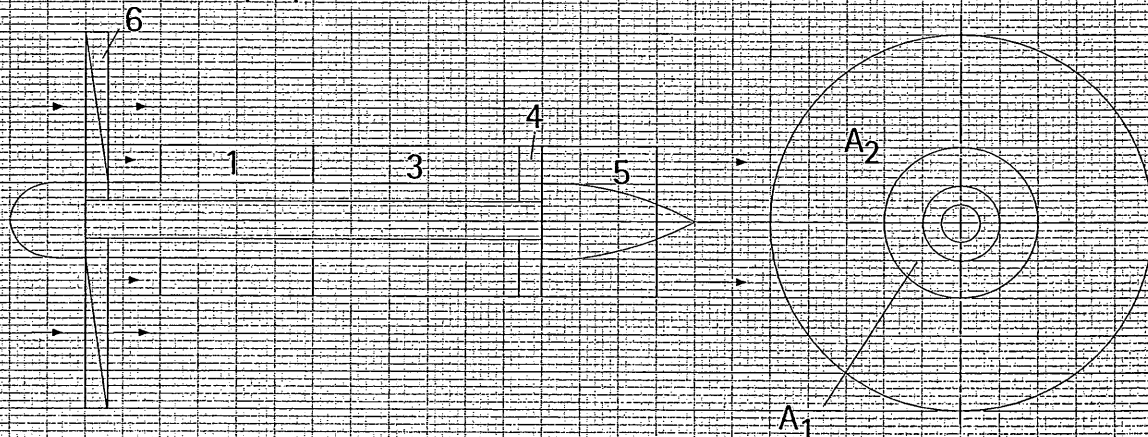
Turbojet (TJ)



Turbofan (TF)



Turboprop (PTJ)

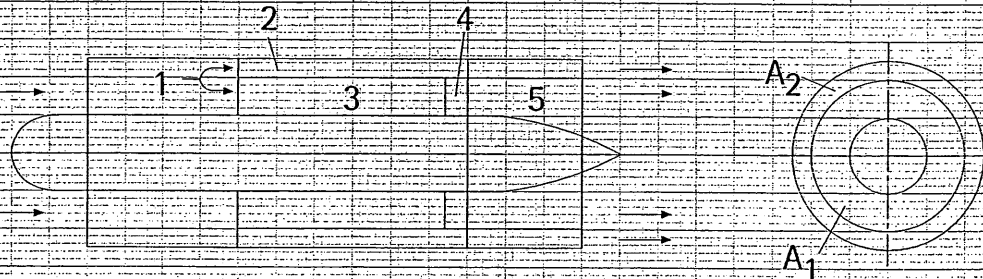


- 1) Compressor
- 2) Fan
- 3) Combustion chamber
- 4) Turbine
- 5) Nozzle
- 6) Propeller

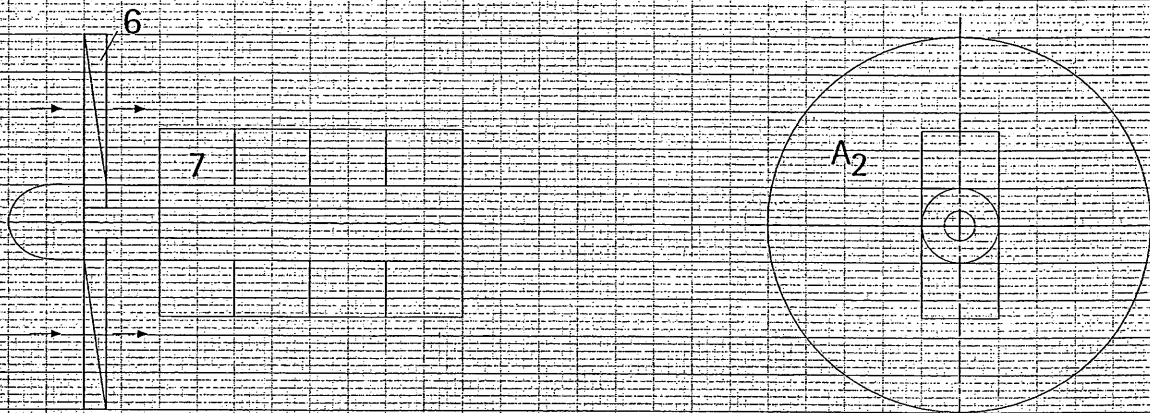
Section 7

Schematic diagrams of various engines

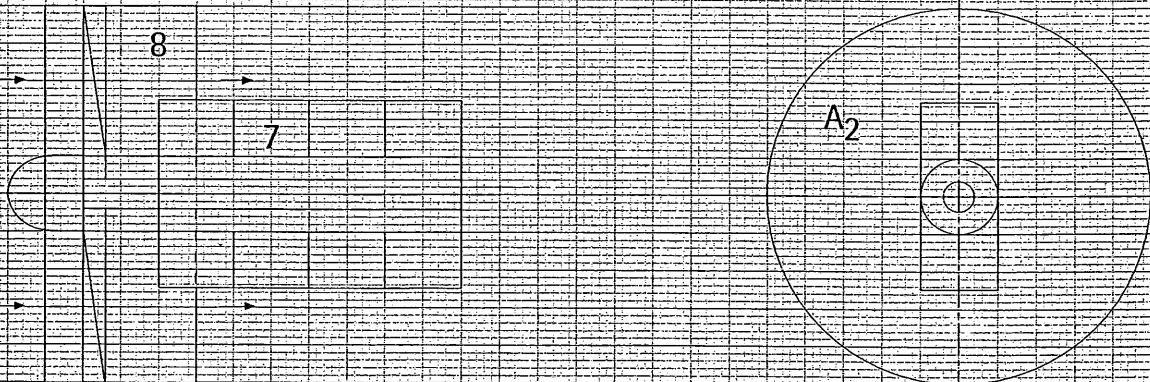
By - pass Turbojet (TJ)



a.) Propeller Piston - engine



b.)



- 1) Compressor
- 2) By - pass
- 3) Combustion chamber
- 4) Turbine
- 5) Nozzle
- 6) Propeller
- 7) Cylinder
- 8) Propeller fan (ducted fan)

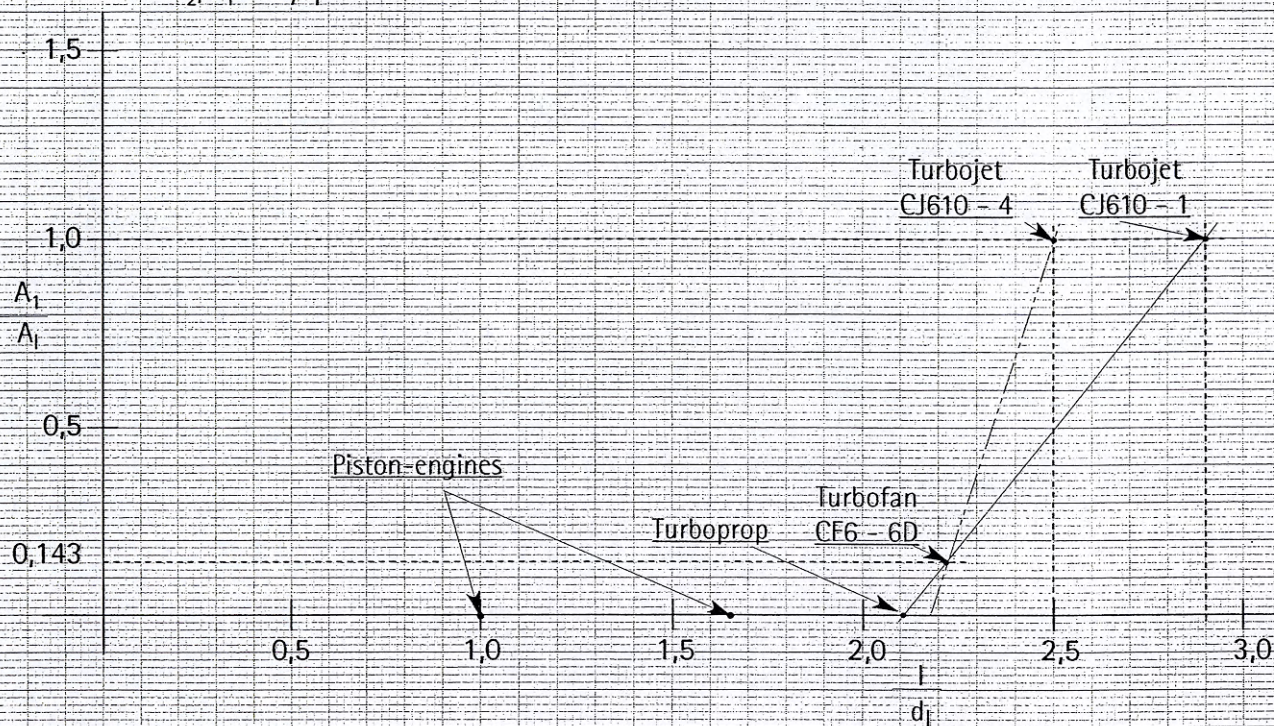
Section 7

A_1 = cross-sectional inlet area of the internal engine

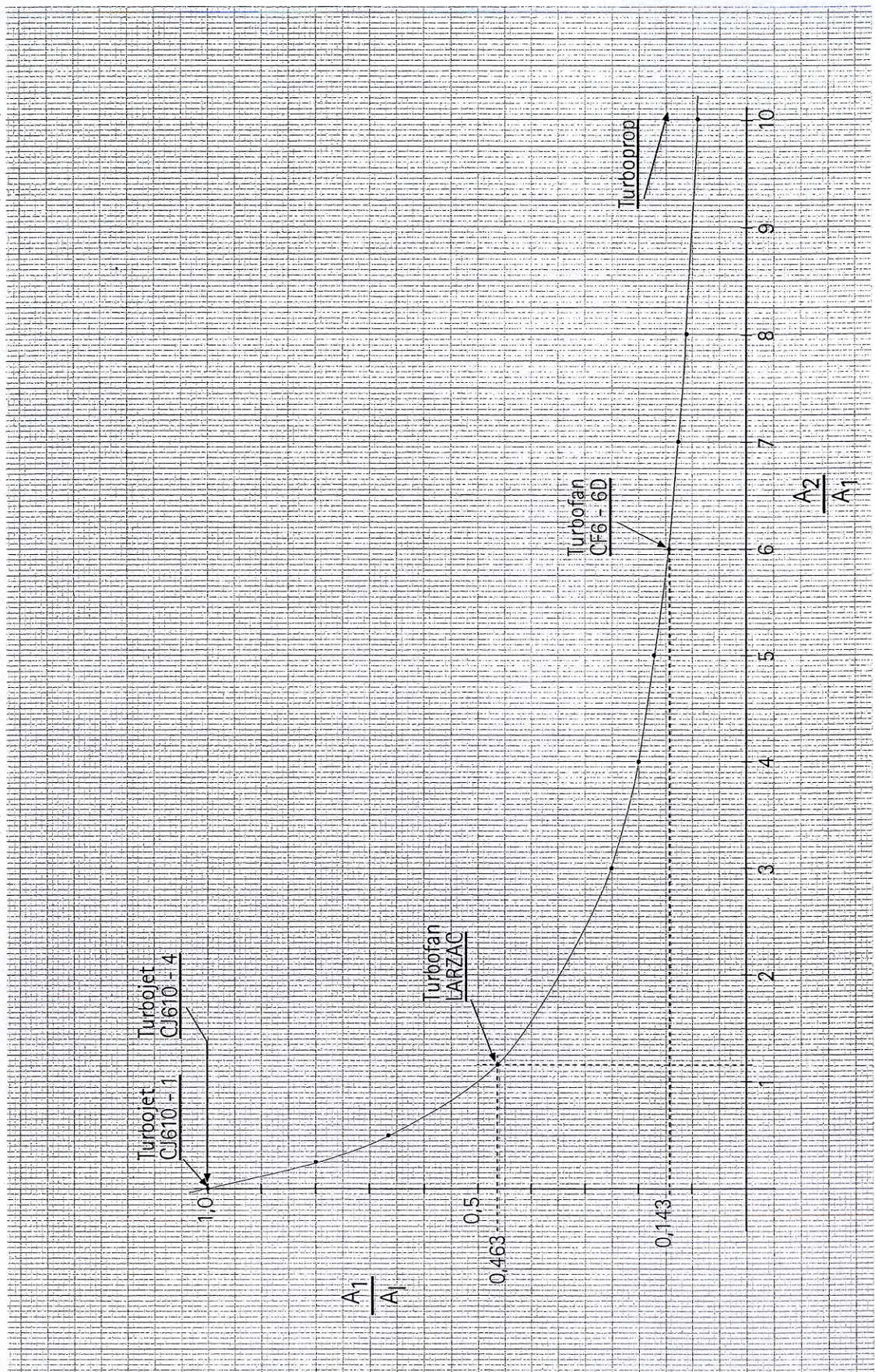
A_1 = cross-sectional inlet area of the overall engine

$A_2 = A_1 - A_1$ = cross-sectional inlet area of the external engine

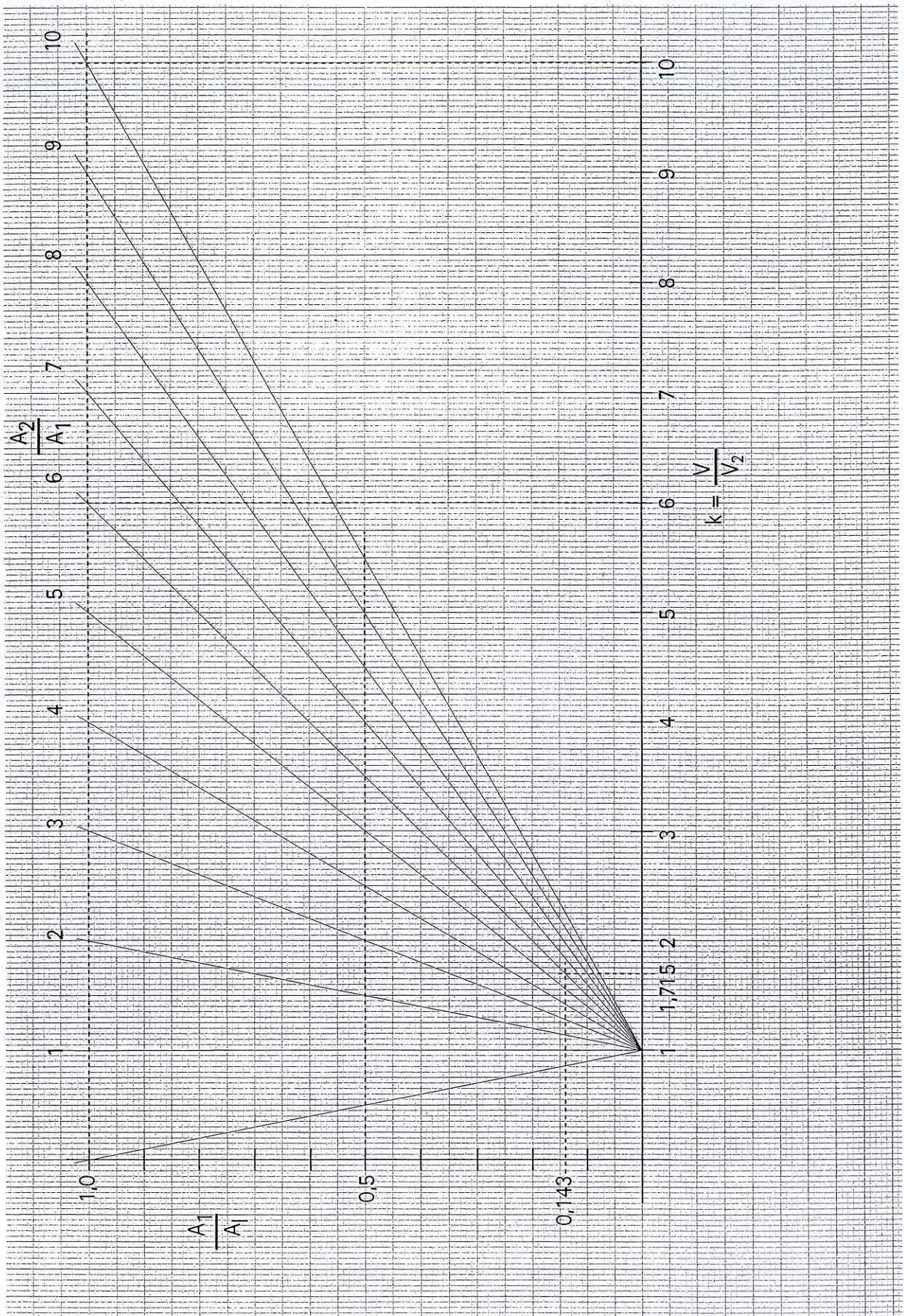
A_2/A_1 = by-pass ratio



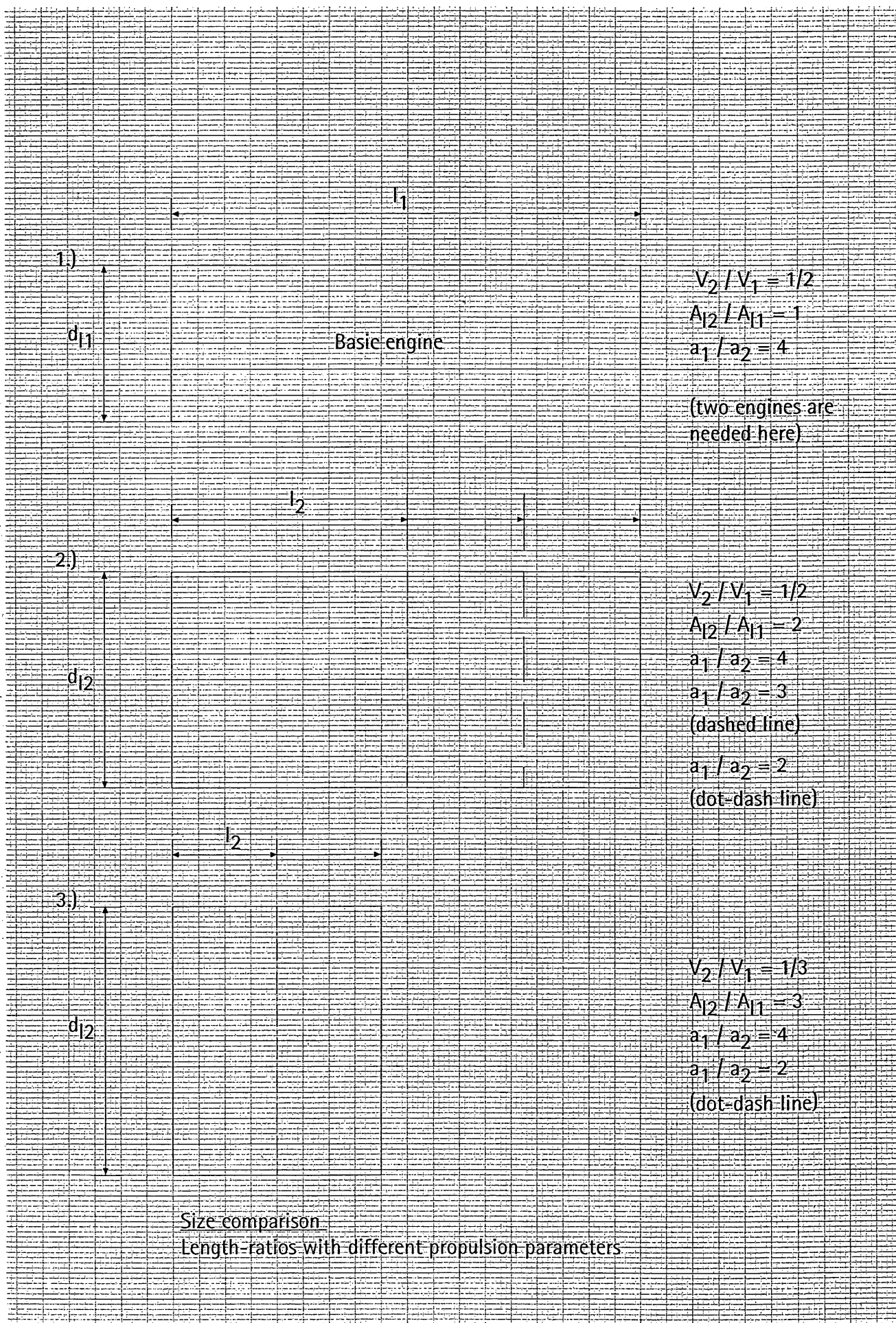
Section 7



Section 7

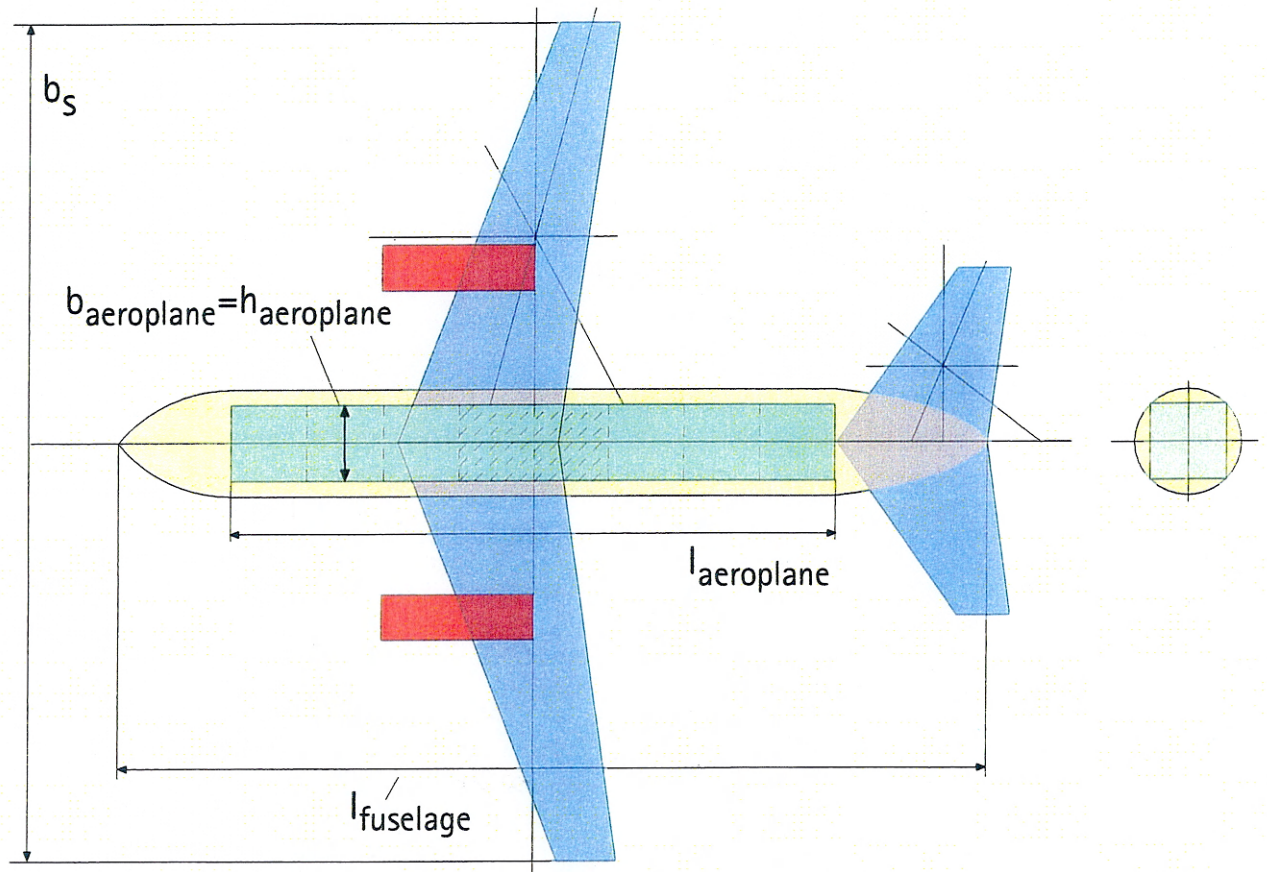


Section 7



Section 7

Schematic diagram 1 Transport aircraft



- Wings
- Horizontal stabiliser
- Engines
- Fuselage
- Overall cargo
- Cargo

Section 9

re. study phase 9

Problem and solution:

18 main points are listed in the research plan, along with the associated subsidiary points, which are to be studied where possible.

The study points of the research plan are designed in such a way that in order to work on any one point, the points before it must first be dealt with or the relevant results obtained.

It is now possible to list study or research aims that have to be achieved in order to solve the overall problem.

Aims

1. Matrix of the configurations
 - contains all possible configurations for large transport aircraft
 - contains configurations for civil and military transporters
2. It should be possible to read off the most important data from the matrix.
 - It is then possible to select an aircraft which has the required features.
3. Special features of the configurations which produce main advantages, such as:
 - better loading and unloading
 - cargo size, civil and military
 - specific weight of cargo
4. Elaboration of the aerodynamic characteristics, such as C_{D0} , C_{Di}
 - possible bogie-landing gear, $\Delta C_{D0, \text{landing gear}}$
 - number of engines and their position on the aircraft, $\Delta C_{D0, \text{engine}}$
5. Size or take-off weight of the transporters, e.g. 200 t to 1000 t
 - is mainly dependent on the length of the available runways
 - influence of wing loading on the runway length
6. Development of small computer programs to calculate trends
7. Study results for the various configurations with regard to the transport capacity and other important features
 - range, payload
 - flying speed, climbing and sinking speed
 - flight characteristics of the pitch, roll and yawing movement
8. Study results for the various configurations with regard to fuselage and landing gear arrangement

Section 9

Calculation of the runway length:

For point 5, a formula was developed which clearly shows how the runway length depends on the wing loading W/S :

$$l_1 = V_{TO}^2 / (2 \times b) \quad (57)$$

If V_{TO} increases, l_1 also increases, as the acceleration remains approximately the same even with larger aircraft masses.

$$b = F/m = F/(W/g) = (F/W) \times g \quad (58)$$

$$F/W = \text{constant} \approx 0.2 \quad (59)$$

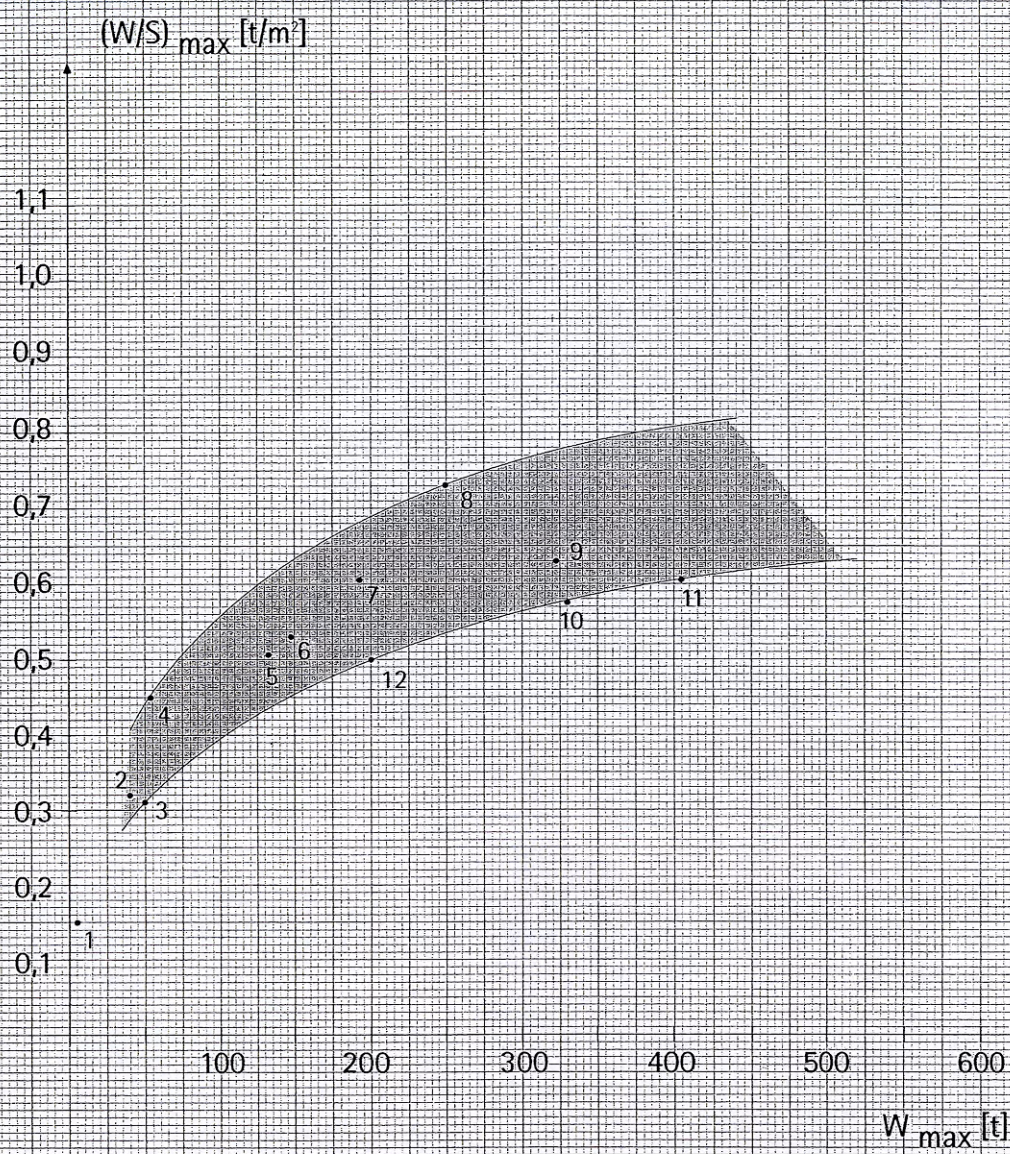
$$V_{TO} = \sqrt{(2/\rho) \times (W/S) \times (1/C_{L, TO})} \quad (60)$$

Results:

The diagram on page 3 shows the dependence $(W/S)_{\max} = f(W_{\max})$ for large transport and passenger aircraft.

The wing loading for configuration 1, page 6 in section 3 of 0.5 t/m^2 was entered in the diagram.

Section 9



Wing area load of built aeroplanes 1 to 11

- 1 CASA C. 212
- 2 NAMC XC-1
- 3 Transall C-160
- 4 Dassault Mercure
- 5 Airbus A 300B
- 6 Boeing 707
- 7 Lockheed L-1011
- 8 An - 22
- 9 Boeing 747
- 10 Lockheed C-5A
- 11 An-124
- 12 Configuration 1

Section 8

re. study phase 8

Problem and solution:

In study phases 3 and 4, 11 configurations were shown for large transport aircraft that were developed with the aid of the new design method in accordance with study phase 5.

In order to be able to compare the configurations with one another, comparative factors must be defined.

The following are suitable for this:

- maximum flying weight
- maximum payload
- aircraft polars
- flying performance
- take-off and landing distances

The maximum flying weight and the maximum payload can be taken directly from the configuration drawing.

For flying performance as well as take-off and landing distances of a configuration, aircraft polars without and with landing flap extension are required.

In the summary of study phase 6, equations of a corresponding variable aircraft polar are given which can be adapted to a certain aircraft configuration.

Adaptation is carried out by more precise definition of the polar constants C_{D0} , k , $\Delta C_{L, flap}$ and $\Delta C_{D, flap}$ for a configuration.

With a comparison of the configurations based on the above-mentioned comparative factors, it is expedient to begin with the basic configurations 1, 2, 4 and 5 from study phase 3.

These are configurations which differ considerably from each other but do not represent an extended, already existent configuration principle.

Basic configuration 3 is an extension of configuration 2 by one rear elevator and is therefore not included in the first comparison.

For basic configurations 1, 2, 4 and 5, the polar constants can be estimated with good accuracy or determined with table calculation.

Section 8

Formulae for estimating C_{D0} and k :

$$C_{D0, P1} = 2 \cdot (C_{D \text{ profile}, P1} + C_{D \text{ interference}, P1}) \quad \text{for configuration 1} \quad (61)$$

$$C_{D0, P2} = C_{D0, P1} + \Delta C_{D \text{ interference}, P2} \quad \text{for configuration 2} \quad (62)$$

$$\Delta C_{D \text{ interference}, P2} = \Delta C_{D \text{ profile}, P1} \cdot (\Delta S/S) \quad (63)$$

$$C_{D0, P4} = (3/2) \cdot C_{D0, P1} \quad \text{for configuration 4} \quad (64)$$

$$C_{D0, P5} = C_{D0, P1} - \Delta C_{D \text{ rear elevator}} \quad \text{for configuration 5} \quad (65)$$

$$\Delta C_{D \text{ rear elevator}} = (C_{D \text{ profile}, P1} + (1/2) \cdot C_{D \text{ interference}, P1}) \cdot (S_{\text{rear elevator}}/S) \quad (66)$$

$$k_{P1} = k_{P2} = k_{P5} = 1/(\pi \cdot A_S) \quad \text{for configurations 1, 2 and 5} \quad (67)$$

$$k_{P4} = (1/2) \cdot k_{P1} \quad \text{for configuration 4} \quad (68)$$

Formulae for calculating $\Delta C_{L, \text{flap}}$ and $\Delta C_{D, \text{flap}}$:

$$\Delta C_{L, \text{flap}} = (dC_L/d\alpha)_S \cdot \sin \eta / (l_1/l_2 + \cos \eta) \cdot S_{\text{flap, area}}/S \quad (69)$$

$$\Delta C_{D, \text{flap}} = 1,0 \cdot (l/b)_{\text{flap}} \cdot S_{\text{flap}}/S \cdot |\sin \eta| \quad (70)$$

Formulae for the quadratic aircraft polar without flap extension for configurations 1, 2, 4 and 5:

$$C_{D, P1} = C_{D0, P1} + k_{P1} \cdot C_L^2 \quad (71)$$

$$C_{D, P2} = C_{D0, P2} + k_{P2} \cdot C_L^2 \quad (72)$$

$$C_{D, P4} = C_{D0, P4} + k_{P4} \cdot C_L^2 \quad (73)$$

$$C_{D, P5} = C_{D0, P5} + k_{P5} \cdot C_L^2 \quad (74)$$

Formula for the quadratic aircraft polar with flap extension for configuration 1:

$$C_{D, \text{flap}, P1} = C_{D0, P1} + \Delta C_{D, \text{flap}, P1} + k_{P1} \cdot (C_{L, \text{flap}} - \Delta C_{L, \text{flap}, P1})^2 \quad (75)$$

Section 8

Formulae for calculating flying performance:

$$R_{Tmax} = k_R \cdot (V/\varepsilon)_{Tmax} \cdot 3.6 \quad \text{range with maximum flying time} \quad (76)$$

$$R_{max} = k_R \cdot (V/\varepsilon)_{Rmax} \cdot 3.6 \quad \text{maximum range} \quad (77)$$

$$(V/\varepsilon)_{Tmax} = (2 \cdot W/(\rho \cdot S))^{1/2} / (2 \cdot (C_{D0}^3 \cdot k)^{1/4}) \quad (78)$$

$$(V/\varepsilon)_{Rmax} = (2 \cdot W/(\rho \cdot S))^{1/2} / ((4/3)^{1/2} \cdot 2 \cdot ((1/3) \cdot (C_{D0}^3 \cdot k))^{1/4}) \quad (79)$$

$$(V/\varepsilon)_{Rmax} = (27/16)^{1/4} \cdot (V/\varepsilon)_{Tmax} \quad (80)$$

Formulae for calculating C_D for maximum flying time and maximum range for configurations 1, 2 and 5:

$$C_D = k_{Tmax} \cdot C_L^2 \quad \text{maximum flying time} \quad (81)$$

$$k_{Tmax} = 2 \cdot k_{P1} \quad (82)$$

$$C_D = k_{Rmax} \cdot C_L^2 \quad \text{maximum range} \quad (83)$$

$$k_{Rmax} = 4 \cdot k_{P1} \quad (84)$$

Formulae for calculating C_{D0} of the main aircraft elements:

$$C_{D0, \text{fuselage body}} = 1/(1 + a \cdot (l/d)_{\text{fuselage}}) \quad (85)$$

$$C_{D0, \text{engine gondola}} = 1/(1 + a \cdot (l/d)_{\text{engine gondola}}) \quad (86)$$

$$a = 5.25 \quad (87)$$

$$C_{D0, \text{wing}} = C_{D, \text{profile}} \quad (88)$$

Formulae for calculating ΔC_D of the landing gear:

$$\Delta C_{D, \text{landing gear}} = C_{D0, P1} \quad \text{configurations 1, 2 and 5} \quad (89)$$

$$\Delta C_{D, \text{landing gear}} = 2 \cdot C_{D0, P1} \quad \text{configuration 4} \quad (90)$$

Section 8

Results:

The following data belong to configurations 1, 2, 4 and 5 from section 3 for the maximum flying weight and the maximum payload:

$W_{\max} = 200 \text{ t}$	for configurations 1, 2 and 5
$W_{\text{Pay}} = 50 \text{ t}$	
$W_{\max} = 250 \text{ t}$	for configuration 4
$W_{\text{Pay}} = 62.5 \text{ t}$	

These payload data refer to medium-range transport, see section 1.

Page 5 shows a comparative diagram of the quadratic aircraft polars without flap extension for the configurations 1, 2, 4 and 5 from section 3.

The flight points discussed in detail in study phase 6 for maximum flying time and maximum range are entered on the individual aircraft polars.

Page 6 shows a comparative diagram for lines which result from connecting the flight points entered in the polar comparative diagram for the longest flying time or greatest range.

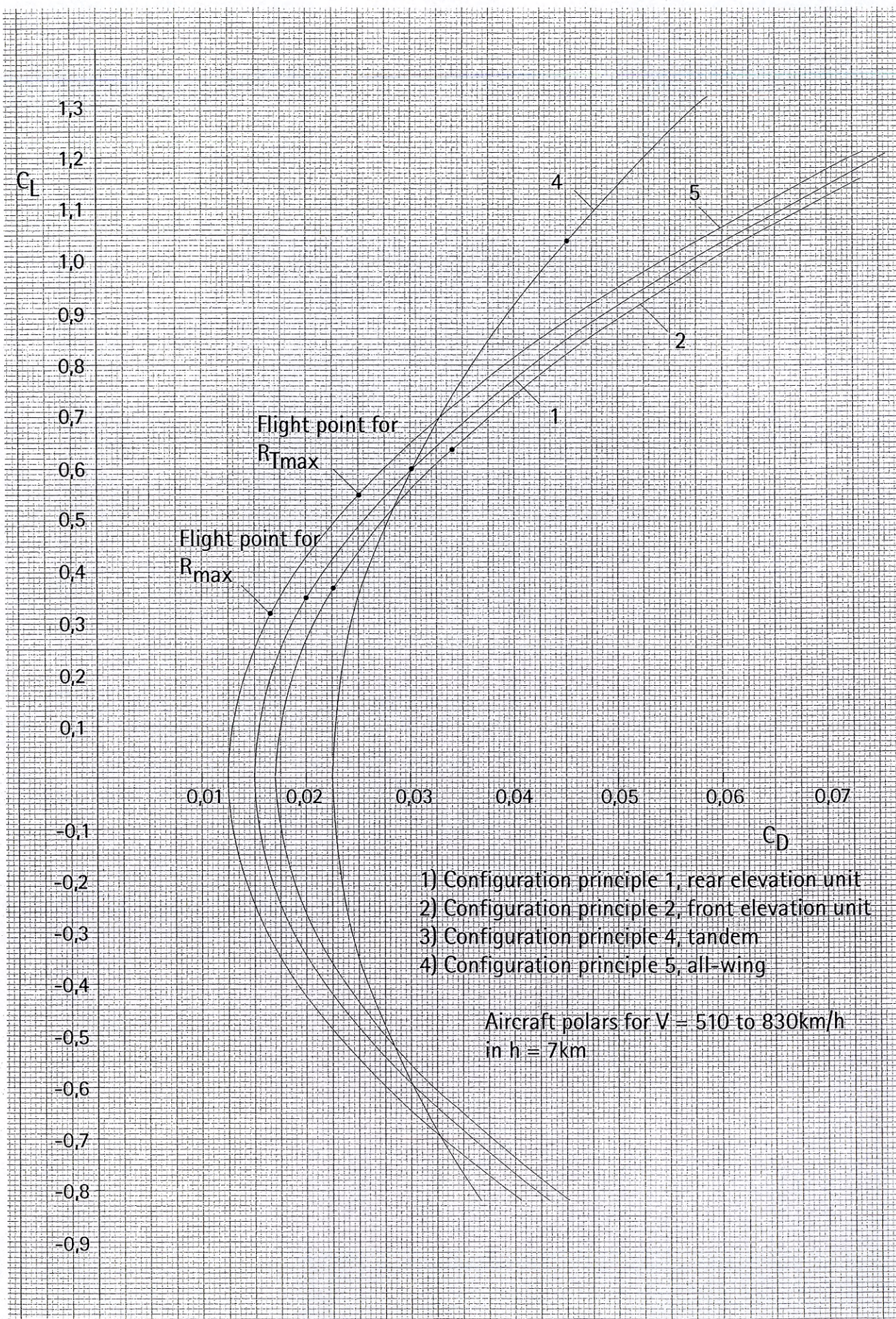
This diagram can be used to read off the C_L values for the longest flying time or the greatest range with larger C_D values than those belonging to configurations 1, 2 and 5.

For example, the corresponding C_D values are larger when the landing gear is extended.

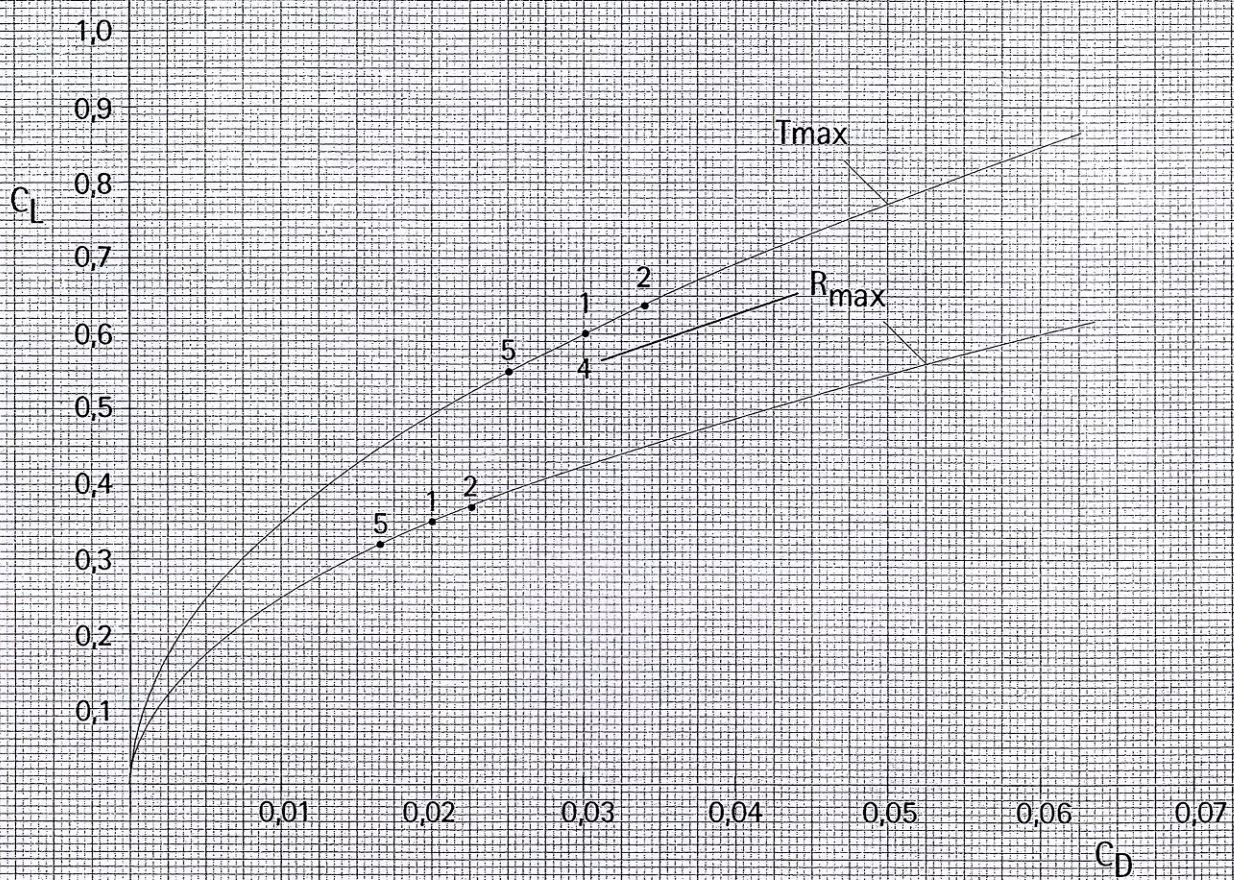
Page 7 shows a results table for flying performance for configurations 1, 2, 4, and 5 from section 3.

The range values given are obtained using the flying performance formulae described on page 3.

Section 8



Section 8



- 1) Configuration principle 1, tail elevation unit
- 2) Configuration principle 2, front elevation unit
- 3) Configuration principle 4, tandem
- 4) Configuration principle 5, all-wing

Connecting line of the flight points
for longest flying time and greatest range

Section 8

Results table for the configuration principles 1, 2, 4 and 5

Configuration principle	1	2	4	5
C_L for T_{max}	0.6012	0.6400	1.0413	0.5466
C_D for T_{max}	0.0300	0.0340	0.0450	0.0248
C_L for R_{max}	0.3471	0.3695	0.6012	0.3156
C_D for R_{max}	0.0200	0.02267	0.0300	0.01653
(C_D/C_L) for T_{max}	0.0499	0.05313	0.0432	0.04537
(C_D/C_L) for R_{max}	0.05762	0.06135	0.0499	0.05238
V for T_{max}	166.333	161.212	141.304	174.442
V for R_{max}	218.907	212.168	185.966	229.572
(V/ϵ) for T_{max}	3333.316	3034.647	3269.795	3844.843
(V/ϵ) for R_{max}	3799.159	3458.750	3726.760	4382.173
R for T_{max}	3749.980	3413.978	3678.519	4325.448
R_{max}	4274.054	3891.094	4192.605	4929.945
C_{D0, P_i}	0.0150	0.0170	0.0225	0.0124
k_{P_i}	0.0415	0.0415	0.02075	0.0415

V (m/s)
 R (km)
 $h = 7km$

Section 10 and 10a

re. study phases 10 and 10a

Problem and solution:

In study phases 10 and 10a, it was to be proven that the range formulae for transport aircraft given in study phase 8 are applicable.

Applicability can only be proven by recalculating the ranges of constructed aircraft whose performances are well known.

For this reason, certain ranges of 10 transport aeroplanes already constructed or in use are calculated in study phases 10 and 10a.

The new range formulae described in study phase 8 are used for the calculations.

In order to calculate the ranges, the data of the main weight shares $W_{\max}$, W_E , W_{Pay} , the size of the wing surface S and the data of C_{D0} and k of the symmetrical aircraft polars for each constructed aeroplane must be given.

In addition, the specific fuel consumption SFC of the engines of the individual aeroplanes in distance flight must be known.

Apart from the data for C_{D0} and k , values for the above-mentioned parameters can be found in specialist literature.

The C_{D0} value must be either estimated or defined by spreadsheet analysis.

As spreadsheet analysis is very time-consuming, approximate formulae were developed in study phase 10 with which the C_{D0} value of an already constructed transport aeroplane of any category can be calculated.

The k -value can be defined exactly when the wing geometry (surface area, aspect ratio and taper ratio) of the individual aeroplane is known.

Otherwise it can also be calculated with an approximate formula, which is given in study phase 3, but which should only be used for wings with a trapezoidal outline and medium tapering.

For large passenger and transport aircraft, fuel reserves are required which are sufficient to fly to an alternative airport and circle there for some time.

The range formulae from study phase 8, which do not contain range or flying time reserves, were amended in this respect.

Section 10 and 10a

Formulae for calculating certain ranges

Ranges with maximum payload:

$$R_{\max} = k_R \cdot (V/\varepsilon)_{R_{\max}} \cdot 3.6 = R \quad (91)$$

$$R_{\text{less reserves}} = R - \Delta R - R_{\text{hold}} \quad (92)$$

$$R_{T_{\max}} = k_R \cdot (V/\varepsilon)_{T_{\max}} \cdot 3.6 = R \cdot (16/27)^{1/4} \quad (93)$$

$$R_{T_{\max}, \text{ less reserves}} = (R - R_{\text{hold}}) \cdot (16/27)^{1/4} - \Delta R \quad (94)$$

$$(V/\varepsilon)_{R_{\max}} = (2 \cdot W_{\max}/(\rho \cdot S))^{1/2} / ((4/3)^{1/2} \cdot 2 \cdot ((1/3) \cdot (C_{D0}^3 \cdot k))^{1/4}) \quad (95)$$

$$(V/\varepsilon)_{T_{\max}} = (2 \cdot W_{\max}/(\rho \cdot S))^{1/2} / (2 \cdot (C_{D0}^3 \cdot k)^{1/4}) \quad (96)$$

$$k_R = (1 - W_E/W_{\max} - W_{\text{Pay}}/W_{\max})/\text{SFC} \quad (97)$$

$$R_{\text{hold}} = (W_{\text{Fuel}}/W_{\max})_{\text{hold}}/\text{SFC} \cdot (V/\varepsilon)_{R_{\max}} \cdot 3.6 \quad (98)$$

$$(W_{\text{Fuel}}/W_{\max})_{\text{hold}} = \varepsilon \cdot \text{SFC} \cdot T_{\text{hold}} \quad (99)$$

Ranges without payload or with maximum fuel amount and payload:

$$R_{\max, \text{ Ferry}} = k_{R, \text{ Ferry}} \cdot (V/\varepsilon)_{R_{\max, \text{ Ferry}}} \cdot 3.6 = R_{\text{Ferry}} \quad (100)$$

$$R_{\text{less reserves, Ferry}} = R_{\text{Ferry}} - \Delta R - R_{\text{hold}} \quad (101)$$

$$R_{T_{\max, \text{ Ferry}}} = k_{R, \text{ Ferry}} \cdot (V/\varepsilon)_{T_{\max, \text{ Ferry}}} \cdot 3.6 = R_{\text{Ferry}} \cdot (16/27)^{1/4} \quad (102)$$

$$R_{T_{\max, \text{ less reserves, Ferry}}} = (R_{\text{Ferry}} - R_{\text{hold}}) \cdot (16/27)^{1/4} - \Delta R \quad (103)$$

$$(V/\varepsilon)_{R_{\max, \text{ Ferry}}} = (V/\varepsilon)_{R_{\max}} \quad (104)$$

$$(V/\varepsilon)_{T_{\max, \text{ Ferry}}} = (V/\varepsilon)_{T_{\max}} \quad (105)$$

$$k_{R, \text{ Ferry}} = (1 - W_E/W_{\max})/\text{SFC} \quad \text{without payload} \quad (106)$$

$$W_{\max} = W \quad (107)$$

$$k_{R, \text{ Ferry}} = (1 - W_E/W_{\max} - W_{\text{Pay, Ferry}}/W_{\max})/\text{SFC} \quad \text{with payload} \quad (108)$$

Section 10 and 10a

Formulae for calculating C_{D0} values:

	Thrust generation by	
$C_{D0} = A_I/S$	1 TJ engine	(109)
$C_{D0} = n_{\text{engine}} \cdot A_I/S$	n TJ engines	(110)
$C_{D0} = 3 \cdot A_I/S$	1 PTJ engine	(111)
$C_{D0} = n_{\text{engine}} \cdot 3 \cdot A_I/S$	n PTJ engines	(112)
$C_{D0} = (V_2/V_1) \cdot A_I/S$	1 TJ engine with throttle setting	(113)
$C_{D0} = n_{\text{engine}} \cdot (V_2/V_1) \cdot A_I/S$	n TJ engines with throttle setting	(114)
$C_{D0} = (V_2/V_1) \cdot (A_{I1}/A_{I2}) \cdot A_{I2}/S$	1 TJ engine with throttle setting and different S_I cross-sectional area	(115)
$C_{D0} = n_{\text{engine}} \cdot (V_2/V_1) \cdot (A_{I1}/A_{I2}) \cdot A_{I2}/S$	n TJ engines with throttle setting and different S_I cross-sectional area	(116)

Formula for calculating the k-value:

$$k = 1/(\pi \cdot A_S) \cdot (1 + \delta) \quad (117)$$

Explanations:

The formulae for calculating C_{D0} -values apply to different aircraft categories.

Aircraft categories differ in terms of aircraft size as well as type and number of engines.

To make this clear, it is possible to write:

$$C_{D0} = C_{D0, \text{ aeroplane category } i} \quad (118)$$

Section 10 and 10a

Results:

The ranges of 10 transport aeroplanes which were already constructed or in use were recalculated with maximum payload and without payload or the ranges with maximum fuel quantity and payload.

The formulae given in study phases 10 and 10a were used for the calculation.

The calculations include a fuel reserve to reach an alternative airport and circling at the destination airport.

In order to make the calculations, the data tables shown on pages 5, 6 and 7 were produced for the transport aeroplanes under study.

The table on page 5 contains the ranges, flying speeds and flying heights of the aircraft with maximum payload.

The table on page 6 contains the ranges, flying speeds and flying heights of the aircraft without payload or with maximum fuel amount and payload.

The table on page 7 contains descriptions and data of the engines of the individual aeroplanes.

A list of abbreviations with explanations belonging to the data tables is given on page 8.

Pages 9 and 10 contain tables of results in which the calculated ranges are compared with the actual ranges of aircraft studied (given in per cent).

Apart from the performances of the 10 constructed transport aircraft, for the purpose of comparison the tables of results also include the corresponding calculated ranges for configuration 1 (see phase 3).

Page 11 shows a diagram for configuration 1 from phase 3, in which the true ratios of $R_{\text{less reserves}}$, ΔR and R_{hold} to R are shown.

These flying distances belong to a flying height of 7 km.

Section 10 and 10a

Type of Transport Aircraft	Max Take-Off Weight $W_{\max}$ [t]	Max Payload W_{Pay} [t]	Empty Weight W_E [t]	$W_E/W_{\max}$ [-]	$W_{\text{Pay}}/W_{\max}$ [-]	Range with Max W_{Pay} [km]	Flight Speed V [km/h]	Flight Altitude h [km]	Flight Time T [h]
Lockheed C-5A Galaxy, ZTL (x4) long r. mil. transport.	330,200	Design p.l. 99,800	B.oper.w. 147,528	0,447	0,302	5652 w. Aver.cr.sp. 815 km/h	High-sp.cr. 853 - 890	7,6	6,48
Boeing 737-200 ZTL (x2) all cargo	51,925	16,275	Oper.e.w. 26,805	0,516	0,313	3435 R.f. 321km +45 min cr. cr. at 9,145 km	M.cr.sp. 915	6,675	3,75
Boeing 707-320C ZTL (x4) Freighter	150,590	41,657	B.oper.w. 60,381	0,401	0,277	6317 no R.	M.cr.sp. 966	7,62	6,54
Boeing 747 F ZTL (4x) heavy transport	351,540	116,926	Oper.e.w. 150,657	0,428	0,333	4630 R. FAR 121,645	M.l.sp. 978	9,15	4,73
Lockheed L-1011 ZTL (x3) transport	193,230	38,203	Man.e.w. 99,336 Oper.e.w. 106,265	0,514 0,550	0,198	4629 w. M = 0,82	M.cr.sp. 899,8 M = 0,85	10,67	5,14
Lockheed L-100 PTL (x4) heavy transport	70,308	22,014	Oper.e.w. 30,645	0,436	0,313	3588 R.f. 45 min	M.cr.sp. 575	6,1	6,24
de Havilland Buffalo PTL (x2) utility transport	18,598	6,279	Oper.e.w. 10,505	0,565	0,338	815 R.f. 45 min at cr. pow.	M.cr.sp. 435	3,05	2,62
M.D. DC-9, Srs 30 ZTL (x2) transport	44,450	11,864	Man.e.w. 24,011	0,540	0,267	2388 R.f. 370 km +60 min h. at 3,05 km w. M = 0,8	M.cr.sp. 909	9,15	2,63
Airbus A300 B ZTL (x2) medium r. transport	132,0	28,97	Man.e.w. 70,52 Oper.e.w. 80,03	0,534 0,606	0,219	2070 R.f. 370 km +45 min h. at 1,525 km	M.cr.sp. 937	7,62	2,21
M.D. DC-10, Srs 10 ZTL (x3) long r. transport	195,045	46,820	B.oper.w. 105,142	0,539	0,240	3909 R.f. 370 km w. M = 0,82	M.cr.sp. 930	9,45	4,20

Data: see Jane's, All the World's Aircraft 1971 - 72

Section 10 and 10a

Type of Transport Aircraft	Take-Off Weight $W_{\max}$ [t]	Payload W_{pay} [t]	Empty Weight W_E [t]	$W_E/W_{\max}$ [-]	$W_{\text{pay}}/W_{\max}$ [-]	Range with W_{pay} [km]	Flight Speed V [km/h]	Flight Altitude h [km]	Flight Time T [h]
Lockheed C-5A Galaxy, ZTL (x4) long r. mil. transp.	330,200	0	B.oper.w. 147,528	0,447	0	13565 w. Aver.cr.sp. 815 km/h	High-sp.cr. 853 - 890	7,6	15,57
Boeing 737-200 ZTL (x2) all cargo	51,925	15,993	Oper.e.w. 26,805	0,516	0,308	3555 R.f. 321 km +45 min cr. cr. at 9,145 km	M.cr.sp. 915	6,675	3,88
Boeing 707-320C ZTL (x4) Freighter	126,314	4,106	B.oper.w. 60,381	0,478	0,0325	12086 no R.	M.cr.sp. 966	7,62	12,51
Boeing 747 F ZTL (4x) heavy transport	351,540	54,348	Oper.e.w. 150,657	0,428	0,1546	8985 R. FAR 121.645	M.l.sp. 978	9,15	9,19
Lockheed L-1011 ZTL (x3) transport	193,230	18,145	Man.e.w. 99,336 Oper.e.w. 106,265	0,514 0,550	0,0939	7189 w. M = 0,82	M.cr.sp. 899,8 M = 0,85	10,67	7,99
Lockheed L-100 PTL (x4) heavy transport	53,709	0	Oper.e.w. 30,645	0,570	0	5182 R.f. 45 min	M.cr.sp. 575	6,1	9,01
de Havilland Buffalo PTL (x2) utility transport	18,598	1,815	Oper.e.w. 10,505	0,565	0,0976	3490 R.f. 45 min at cr. pow.	M.cr.sp. 435	3,05	8,02
M.D. DC-9, Srs 30 ZTL (x2) transport	44,450	11,864	Man.e.w. 24,011 Oper.e.w. 80,03	0,540	0,267	2388 R.f. 370 km +60 min h. at 3,05 km w. M = 0,8	M.cr.sp. 909	9,15	2,63
Airbus A300 B ZTL (x2) medium r. transport	132,0	20,484	Man.e.w. 70,52 Oper.e.w. 80,03	0,534	0,1552	3900 R.f. 370 km +45 min h. at 1,525 km	M.cr.sp. 937	7,62	4,16
M.D. DC-10, Srs 10 ZTL (x3) long r. transport	180,433	0	B.oper.w. 105,142	0,583	0	8283 R.f. 370 km w. M = 0,82	M.cr.sp. 930	9,45	8,91

Data: see Jane's, All the World's Aircraft 1971 - 72

Section 10 and 10a

Type of Transport Aircraft	Engines used	Dry Weight W _{Dry} [kg]	Thrust F [kg st]	By-pass Ratio	Spec. Fuel Consumpt. [lb/lbf/hr]	W _{Dry} /F [-]	Total Length l [m]	Diameter d [m]
Lockheed C-5A	Four turbofan General Electric TF39-GE1	3316	18640	8 : 1	(0,763) -25%	0,1779	6,880	2,540 over fan
Boeing 737-200C	Two turbofan Pratt & Whitney JT8D-9	1459	6575	1,1 : 1	0,595	0,2219	3,048	1,080
Boeing 707-320C	Four turbojet Pratt & Whitney JT3C-7	1587	5443	0	0,785	0,2916	?	0,9855
Boeing 747F	Four turbofan Pratt & Whitney JT9D-3	3905	19730	5,13 : 1	(3A) 0,346	0,1979	3,256 flange to flange	2,428
Lockheed L-1011	Three turbofan Rolls - Royce RB. 211-22B	3267	19050	5 : 1	0,638	0,1715	3,033	2,172 Intake diameter
Lockheed L-100	Four turboprop Allison T56-A-7A	831	3730 eshp normal rating		0,246 kg/ehp/hr normal rating	0,2228 kg/eshp	3,708	Width 0,686 Height 0,991
de Havilland Buffalo	Two turboprop General Electric T64 (CT64-820)	513	2480 ehp max continuous		0,236 kg/ehp/hr max continuous	0,2068 kg/ehp	2,870	Width 0,727 Height 0,762?
M.D. DC-9, Srs 30	Two turbofan Pratt & Whitney JT8D-9	1459	6575	1,1 : 1	0,595	0,2219	3,048	1,080
Airbus A300B	Two turbofan General Electric CF6-50A	3731	22226	4,4 : 1	0,654	0,1679	4,827	2,195 Fan tip diam.
M.D. DC-10; Srs 10	Three turbofan General Electric CF6-6D	3379	(20752) 18144	5,9 : 1	0,631 max cruise thrust	0,1862	4,902	2,195 Fan tip diam.

Data: see Jane's, All the World's Aircraft 1971 - 72

Section 10 and 10a

List of the Abbreviations, including Explanations

long r. mil. transport	long range military transport
medium r. transport	medium range transport
long r. transport	long range transport
M.D.	MACDONNEL DOUGLAS
Design p.l.	Design payload
B.oper.w.	Basic operating weight
Oper.e.w.	Operating empty weight
Man.e.w.	Manufacturer's empty weight
w. Aver.cr.sp.	with Average cruising speed
R.f. 321 km	Reserves for 321 km
+45 min cr.	+45 min cruise
cr. at 9,145 km	cruising at 9,145 km
no R.	no Reserves
R. FAR 121.645	Reseres FAR 121.645
w. M = 0,82	with M = 0,82
R.f. 45 min	Reserves for 45 min
at cr. pow.	at cruise power
R.f. 370 km	Reserves for 370 km
+60 min h. at 3,05 km	+60 min hold at 3,05 km
w. M = 0,8	with M = 0,8
+45 min h.	+45 min hold
High-sp.cr.	High-speed cruise
M.cr.sp.	Max cruising speed
M.l.sp.	Max level speed

Section 10 and 10a

Table 1 of Results, range with maximum payload

Aircraft type	Range, minus the reserves, as stated by the manufacturer $R_{\text{less reserves, debit}}$ [km]	Calculated range if the reserves are fully burned up R [km]	Calculated range R , minus the reserves $R_{\text{less reserves}}$ [km]	Difference, compared to the statements of the manufacturer [%]
Lockheed C-5A Galaxy	5652 (no res.)	5965.13	5965.13	+5.5
Boeing 737-200C	3435	4911.47	3394.47	-1.2
Boeing 707-320C	6317 (no res.)	6872.16	6872.16	+8.8
Boeing 747F	4630	5838.74	4630.19	+0.0
Lockheed L-1011	4629	6478.71	4726.06	+2.1
Lockheed L-100	3588	3995.87	3211.97 3603.92	-10.5 +0.4
de Havilland Buffalo	815	1172.14	713.44 942.79	-12.5 +15.7
M.D. DC-9, Srs 30	2388	4221.41	2222.75	-6.9
Airbus A300B	2070	3916.78	2329.69 2123.38	+12.5 +2.6
M.D. DC-10, Srs 10	3909	4375.84	4005.84	+2.5
Configuration Scheme 1 basic engine	-	4273.89	2878.16	-
Configuration Scheme 1, alternative engine	-	4883.86	3488.13	-

Section 10 and 10a

Table 2 of Results, ferry range or range with maximum fuel

Maximum take-off weight without payload (data in the upper line)
or payload and maximum fuel (data in the lower line)
or maximum fuel without payload (data in the lower line)

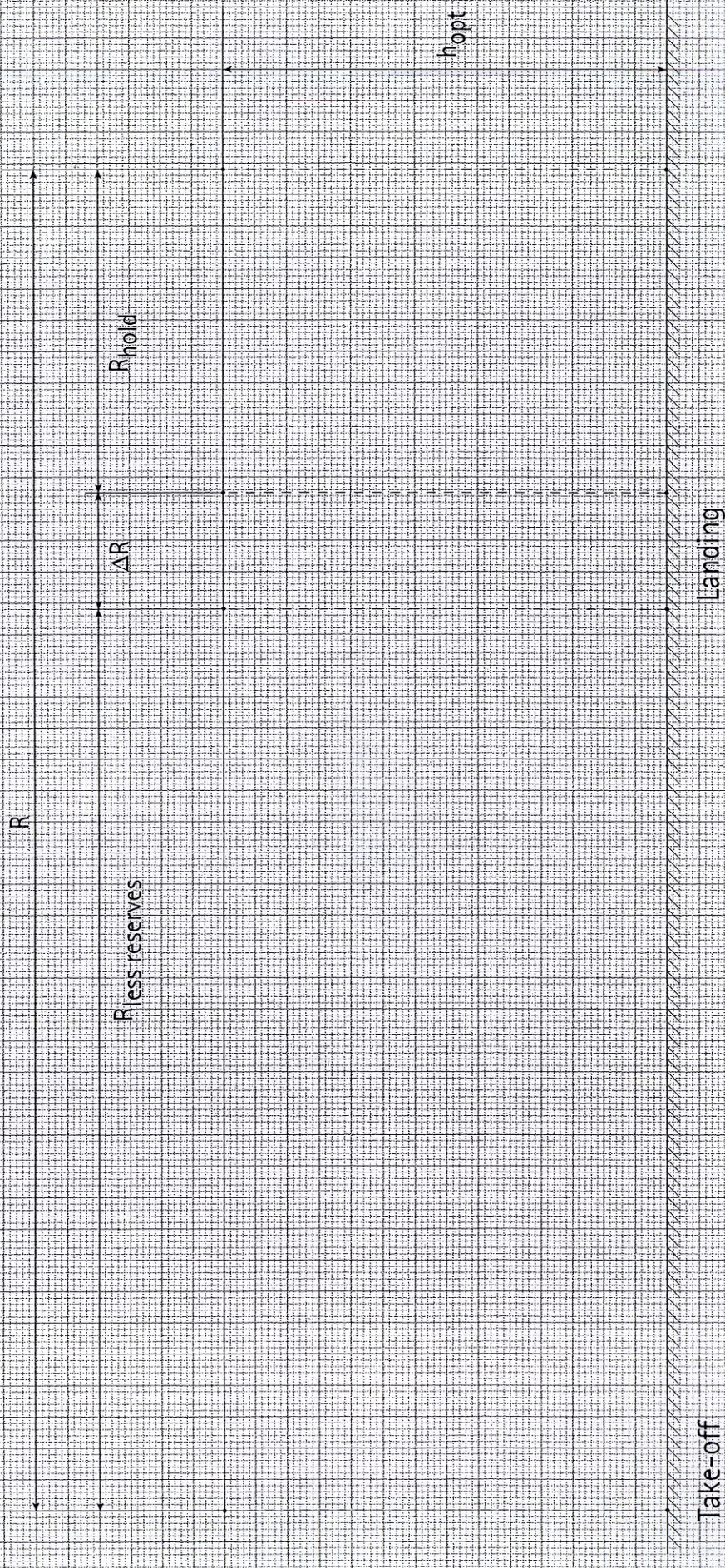
Aircraft Type	Range, minus the reserves, as stated by the manufacturer $R_{\text{less reserves, Ferry, debit [km]}}$	Calculated range, if the reserves are fully burned up $R_{\text{Ferry [km]}}$	Calculated range R_{Ferry} , minus the reserves $R_{\text{less reserves, Ferry [km]}}$	Difference, compared to the statements of the manuf. [%]
Lockheed C-5A Galaxy	13565 (Ferry range)	13138.78	13138.78 (no r.)	-3.1
Boeing 737-200C	3555 (max p.l. - 3 pass.)	13897.09	12380.44 3536.85	+348.3 -0.5
Boeing 707-320C	12086 (no p.l. stated)	12779.56	12779.56 (no r.) 12086	+5.7 0 *)
Boeing 747F	8985 (no p.l. stated)	13968.64	12760.46 8985	+42.0 0 *)
Lockheed L-1011	7189 (18.145 t p.l.)	11567.22	9814.90 7401.23	+36.5 +2.9
Lockheed L-100	5182 (zero p.l.)	8967.82	8184.47 5182	+57.9 0 **)
de Havilland Buffalo	3490 (1.815 t p.l.)	5254.88	4796.27 3617.26	+37.4 +3.6
M.D. DC-9, Srs 30	?	13851.12	11852.80	?
Airbus A300B	3900 (no p.l. stated)	8817.79	7373.05 3900	+89.1 0 *)
M.D. DC-10, Srs 10	8283 (zero p.l.)	10113.80	9743.80 8283	+17.6 0 **)
Configuration Scheme 1 basic engine	-	8527.04	7134.17	-
Configuration Scheme 1 alternative engine	-	9745.19	8352.31	-

Abbreviations: p.l. = payload , no r. = no reserves , pass. = passengers

*) payload: see calculations no. 4

**) take-off weight: see calculations no. 4

Section 10 and 10a



R = range with maximum payload, without reserves
 $R_{\text{less reserves}}$ = range R , minus the reserves
 R_{hold} = range, based on reserve fuel for T_{hold}

T_{hold} = flight time for hold
 ΔR = distance between the alternate airport and the destination airport
 h_{opt} = flight altitude for maximum range

Section 10 and 10a

Results table page 102

Justification/explanation

This table has 5 columns with the following contents:

- 1st column: 10 constructed transport aeroplanes
1 schematic transport aeroplane.
- 2nd column: Range, maximum payload, maximum take-off weight,
if all reserves are still available,
specified by manufacturer, for:
10 constructed transport aeroplanes
1 schematic transport aeroplane
- 3rd column: Calculated range, maximum payload, maximum take-off weight,
if all reserves are used up, for:
10 constructed transport aeroplanes,
1 schematic transport aeroplane
- 4th column: Calculated range, maximum payload, maximum take-off weight,
if all reserves are still available, for:
10 constructed transport aeroplanes,
1 schematic transport aeroplane
- 5th column: Difference in ranges of column 4 and column 2 in relation to the
ranges of column 2 ($R_{\text{less reserves}} - R_{\text{less reserves, debit}} / R_{\text{less reserves, debit}}$)

The 2nd column and 5th column does not contain any values for the schematic transport aeroplane, as in this case there is no manufacturer (yet) and therefore also no difference in the calculated range $R_{\text{less reserves}}$ of the schematic aeroplane for range $R_{\text{less reserves, debit}}$ of the constructed, schematic aeroplane.

For three constructed transport aeroplanes (Lockheed L-100, de Havilland Buffalo and Airbus A300B), the lines of the 4th column and 5th column contain two values.

Here the range reserves were calculated in two different ways in order to determine which method produced the better results.

Section 10 and 10a

Results table page 103

Justification/explanation

This table has 5 columns with the following contents:

- 1st column: 10 constructed transport aeroplanes
1 schematic transport aeroplane
- 2nd column: 1.) Ferry range without payload, maximum take-off weight
2.) Range with maximum fuel and payload,
3.) Ferry range without payload,
if all reserves are still available,
specified by manufacturer, for:
10 constructed transport aeroplanes
1 schematic transport aeroplane
- 3rd column: Calculated range 1.), 2.) or 3.), if all reserves are used up, for:
10 constructed transport aeroplanes,
1 schematic transport aeroplane
- 4th column: Calculated range 1.), 2.) or 3.), if all reserves are still available, for:
10 constructed transport aeroplanes,
1 schematic transport aeroplane
- 5th column: Difference in ranges of column 4 and column 2 in relation to the
ranges of column 2
 $(R_{\text{less reserves, Ferry}} - R_{\text{less reserves, Ferry, debit}}) / R_{\text{less reserves, Ferry, debit}}$

The 2nd column and 5th column does not contain any values for the schematic transport aeroplane, as in this case there is no manufacturer (yet) and therefore also no difference in the calculated range $R_{\text{less reserves, Ferry}}$ of the schematic aeroplane for the range $R_{\text{less reserves, Ferry, debit}}$ of the constructed, schematic aeroplane.

The ranges of column 2 may belong to 1.), 2.) or 3.) depending on the available specifications of the manufacturer.

It is important that when calculating the ranges for the different aeroplane types, the relevant conditions are taken into account.

The lines of the table have two data entries:
the upper entry belongs to 1.), the lower entry to 2.) or 3.).

Section 11

re. Study phase 11

Problem and solution:

In study phase 2 it is shown that a cubic overall aeroplane volume can be defined for a large passenger or transport aeroplane, which can be divided into 8 individual cubic elements.

Dividing the cubic overall aeroplane volume into 8 cubic volume elements is dividing into the smallest number of individual cubic elements.

If one lines the 8 cubic elements up next to one another, this produces a non-cubic overall aeroplane volume of the same size as the cubic one.

The length of the non-cubic overall aeroplane volume, consisting of 8 individual cubic elements, provides the length of an overall aeroplane cargo compartment, if an aeroplane nose and an aeroplane tail are also planned in front and behind it respectively.

The cubic overall aeroplane volume can now be made larger or smaller at will or scaled by altering the lengths of the sides of the volume cube with the aid of a scaling factor.

If, for example, the overall aeroplane volume is to be doubled, the side lengths of the volume cube are to be multiplied by $2^{1/3}$.

To triple the overall aeroplane volume, the side lengths of the volume cube are to be multiplied by $3^{1/3}$ and so on.

If the scaled cubic overall aeroplane volume is converted to a scaled, non-cubic overall aeroplane volume consisting of 8 individual cubic elements, the side length of one of these elements is then $(\text{overall aeroplane volume} / 8)^{1/3}$.

One can now assume that the factors of aeroplane structure, payload, fuel and crew are included in the overall aeroplane volume and set a mean specific weight for this.

Multiplying the overall aeroplane volume by this specific weight then produces the maximum aeroplane weight $W_{\max}$.

The scaling factor can be calculated for different aeroplane weights $W_{\max}$ for a step-by-step scaled aeroplane configuration and shown as a function of $W_{\max}$.

In study phase 11, this is referred to as the scaling factor function and written as follows:

$$k_{\text{scale}} = f(W_{\max, \text{scale}}) \quad (119)$$

Section 11

On the overall aeroplane cargo compartment, consisting of 8 individual cubic elements, wing surfaces are arranged on the side and horizontal stabiliser surfaces at the rear or on the side in accordance with the configurations 1, 2, 4 and 5 from phase 3, which must also be scaled when the overall aeroplane volume is scaled if the scaled configuration should be exactly the same as the unscaled configuration.

If, for example, the overall aeroplane volume is doubled, the surface of the wings or stabilisers attached to the cargo compartment is to be multiplied by $2^{2/3}$.

This corresponds to an enlargement of the wing or stabiliser span and of the wing or stabiliser depth by a factor of $2^{1/3}$.

An overall wing scaled in this way together with the correspondingly scaled overall aeroplane cargo compartment produces a surface load of:

$$(W_{\max}/S)_{\text{scale}} = (W_{\max}/S) \cdot k_{\text{scale}} \quad (120)$$

In addition to the scaling of the overall aeroplane volume, which is referred to in study phase 11 as scaling method 1, and which produces exactly the same aeroplane configurations, there is another scaling method.

With this method, the overall aeroplane cargo compartment, consisting of 8 individual cubic elements, either a) one individual element added or b) one individual element deducted, so that a longer or shorter overall aeroplane cargo compartment results.

The additional cargo compartment element can be used for additional fuel or additional payload.

The deducted cargo compartment element can ensure a reduction in fuel or a reduction in payload.

This scaling method is referred to in study phase 11 as scaling method 2 and produces two dissimilar aeroplane configurations.

It is also possible to scale the configurations resulting from scaling method 2 according to scaling method 1.

This produces two different groups of scaled, exactly similar configurations, the only difference being the length of the overall aeroplane cargo compartment.

This scaling method is referred to in study phase 11 as scaling method 3.

The 3 scaling methods briefly described here can be used for the basic configurations 1, 2, 4 and 5 from phase 3.

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Formulae for scaling:

$$V_{0, \text{acroplane}} = h_{0, \text{acroplane}}^3 \quad \text{not scaled} \quad (121)$$

$$h_{0, \text{acroplane}} = (W_{\max}/W_{\text{spec}})^{1/3} \quad (122)$$

$$V_{0, \text{acroplane, scale}} = h_{0, \text{acroplane, n}}^3 \quad \text{scaled n times} \quad (123)$$

$$h_{0, \text{acroplane, n}} = (W_{\max}/W_{\text{spec}})^{1/3} \cdot n^{1/3} \quad (124)$$

$$k_{\text{scale}} = n^{1/3} \quad (125)$$

$$n = 1, 2, 3, 4 \quad (126)$$

$$V_{0, \text{acroplane, scale, general}} = h_{0, \text{acroplane, general}}^3 \quad \text{generally scaled} \quad (127)$$

$$h_{0, \text{acroplane, general}} = (W_{\max}/W_{\text{spec}})^{1/3} \cdot n_{\text{general}}^{1/3} \quad (128)$$

$$k_{\text{scale, general}} = n_{\text{general}}^{1/3} \quad (129)$$

$$n_{\text{general}} = \text{decimal number} \quad (130)$$

The scaling factor function:

$$k_{\text{scale}} = f(W_{\max, \text{scale}}) = f(W_{\max} \cdot n) \quad \text{scaled n times} \quad (131)$$

$$k_{\text{scale, general}} = f(W_{\max, \text{scale}}) = f(W_{\max} \cdot n_{\text{general}}) \quad \text{generally scaled} \quad (132)$$

The scaling surface load function:

$$(W_{\max}/S)_n = (W_{\max}/S) \cdot k_{\text{scale}} \quad \text{scaled n times} \quad (133)$$

$$(W_{\max}/S)_{\text{scale}} = (W_{\max}/S) \cdot k_{\text{scale, general}} \quad \text{generally scaled} \quad (134)$$

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Results:

The scaling factor functions shown on pages 5 and 6 were calculated for the basic configurations 1, 2, 4 and 5 described in study phase 3.

These functions are required for scaling method 1 given on page 2.

The function shown on page 5 allows scaling of the configurations 1, 2 and 5, whereas the function shown on page 6 only allows scaling of configuration 4.

In addition, the scaling factor functions shown on pages 7 and 8 were calculated for basic configuration 1 described in study phase 3.

These functions are required for scaling method 3 described on page 2.

The scaling factor functions described here were converted to corresponding scaling surface load functions, which are shown on pages 9, 10, 11 and 12.

The conversion produces different ordinate values.

Results according to scaling method 1:

The basic configurations 1, 2 and 5 were scaled to the maximum aeroplane weights $W_{\max} = 400 \text{ t}$, 600 t and 800 t .

Basic configuration 4 was scaled to the maximum aeroplane weights $W_{\max} = 500 \text{ t}$, 750 t and 1000 t .

Results according to scaling method 2:

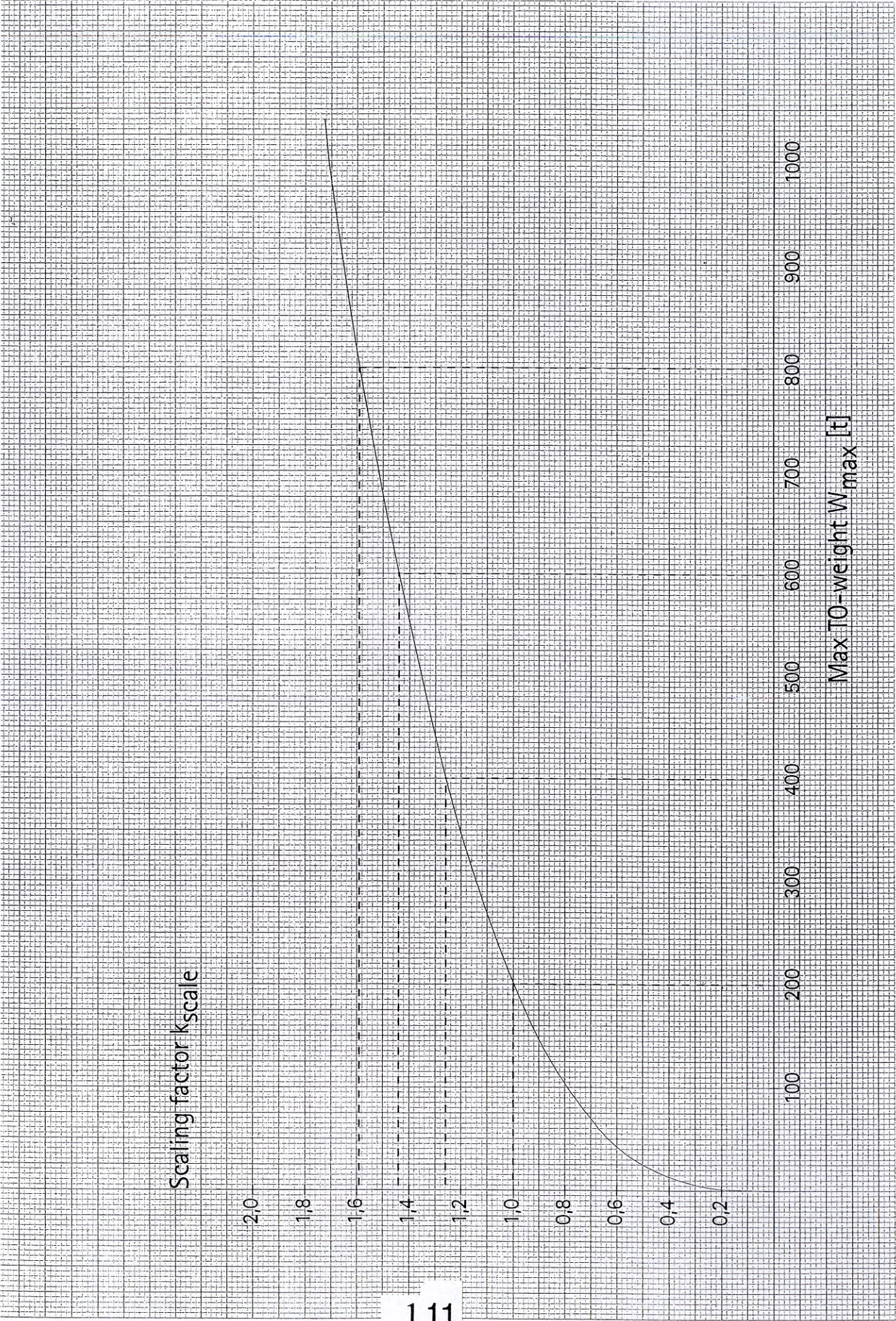
The basic configurations 1, 2 and 5 were scaled to the maximum aeroplane weights $W_{\max} = 225 \text{ t}$ (overall aeroplane cargo compartment with 9 elements) and $W_{\max} = 175 \text{ t}$ (overall aeroplane cargo compartment with 7 elements).

Basic configuration 4 was scaled to the maximum aeroplane weights $W_{\max} = 275 \text{ t}$ (overall aeroplane cargo compartment with 10 elements) and $W_{\max} = 225 \text{ t}$ (overall aeroplane cargo compartment with 8 elements).

Results according to scaling method 3:

Basic configuration 1 was scaled to the maximum aeroplane weights $W_{\max} = 450 \text{ t}$, 675 t and 900 t and $W_{\max} = 350 \text{ t}$, 525 t and 700 t .

Section 11



Section 11

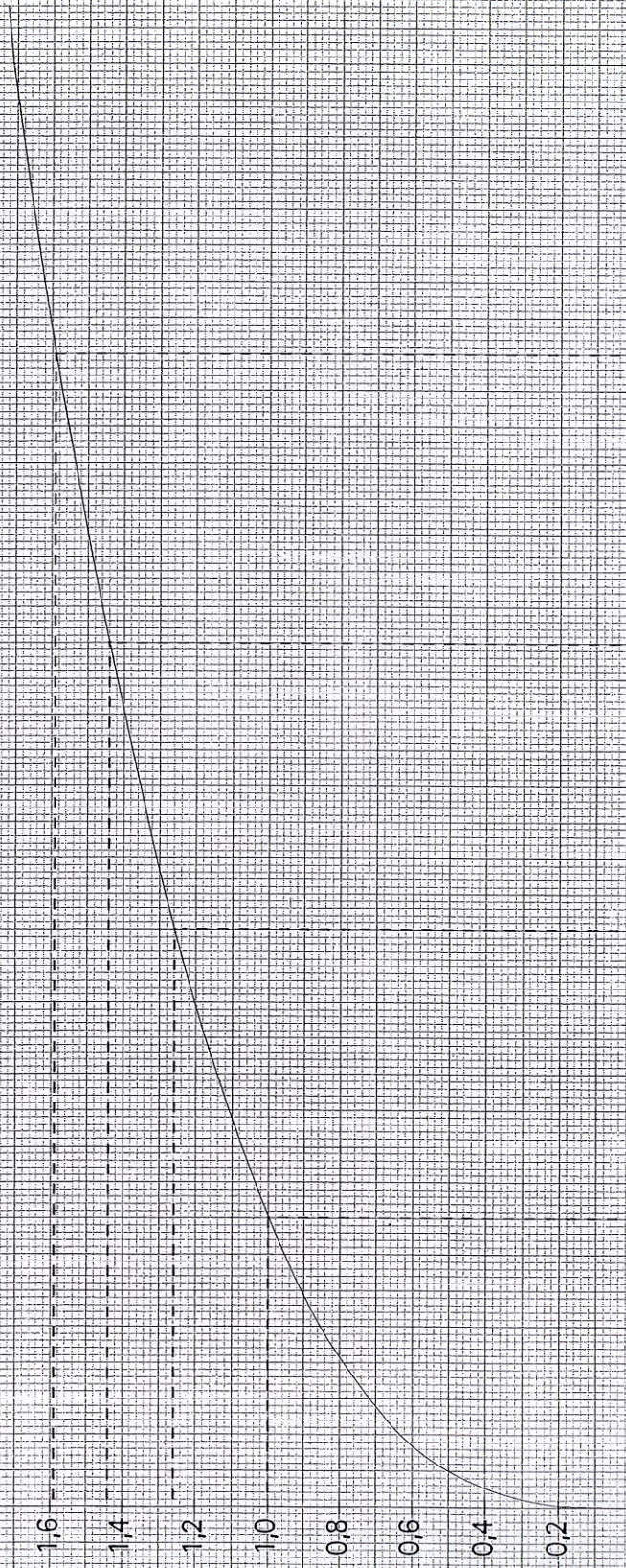
for Schematic diagrams 4, 4.1, 4.2, 4.3

Scaling factor k_{scale}

2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2

125 250 375 500 625 750 875 1000 1125 1250

Max TO-weight W_{max} [t]



for Schematic diagrams 1.4, 1.4.1, 1.4.2, 1.4.3

Scaling factor k_{scale}

2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2

112,5 225 337,5 450 562,5 675 787,5 900 1012,5 1125

Max TO-weight W_{max} [t]

for Schematic diagrams 1.5, 1.5.1, 1.5.2, 1.5.3

Scaling factor k_{scale}

2.0

1.8

1.6

1.4

1.2

1.0

0.8

0.6

0.4

0.2

87,5

175

262,5

350

437,5

525

612,5

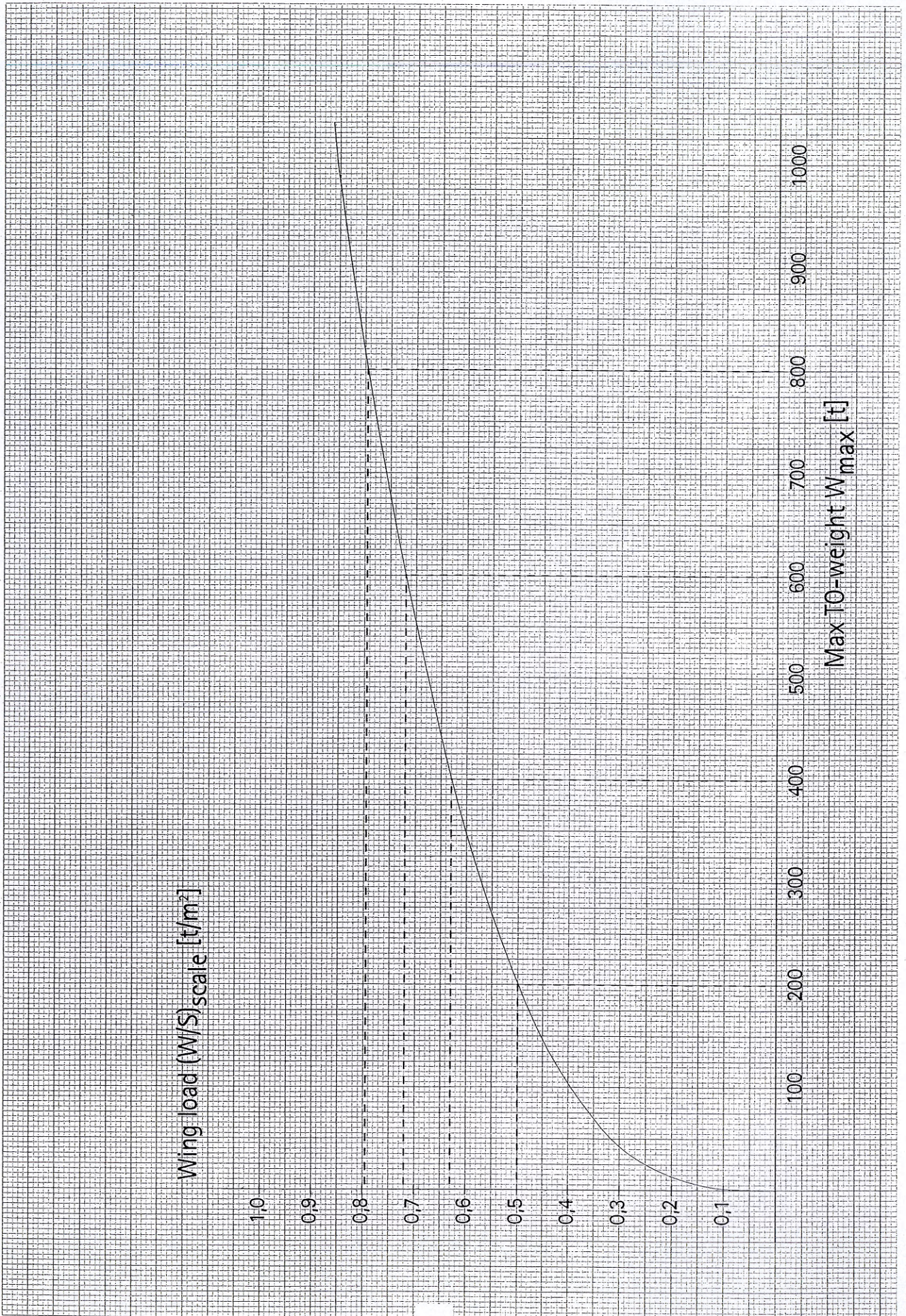
700

787,5

875

Max IO-weight W_{max} [t]

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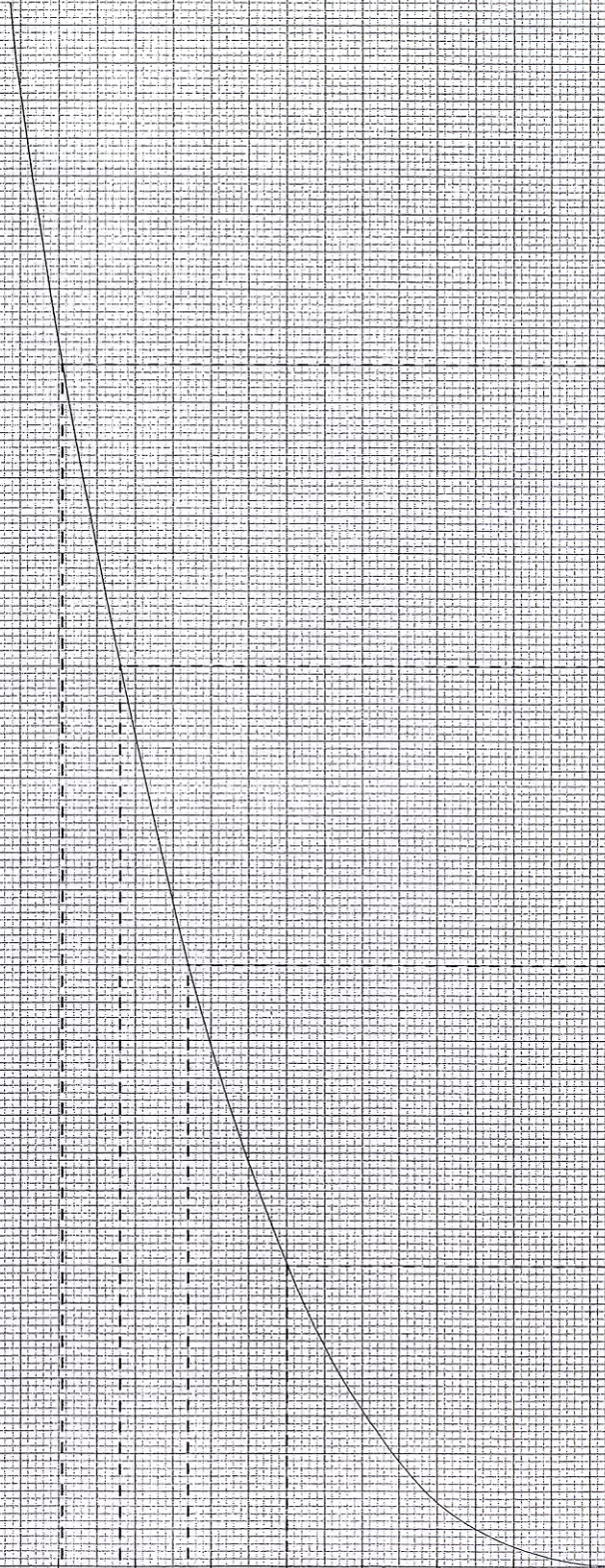


Section 11

for Schematic diagrams 4, 4.1, 4.2, 4.3

Wing load (W/S)_{scale} [t/m²]

1,250
1,125
1,000
0,875
0,750
0,625
0,500
0,375
0,250
0,125



Max TO-weight W_{max} [t]

125 250 375 500 625 750 875 1000 1125 1250

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for Schematic diagrams 1.4, 1.4.1, 1.4.2, 1.4.3

Wing load $(W/S)_{scale}$ [t/m²]

1,1250
1,0125
0,9000
0,7875
0,6750
0,5625
0,4500
0,3375
0,2250
0,1125

112,5 225 337,5 450 562,5 675 787,5 900 1012,5 1125

Max TO-weight W_{max} [t]

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for Schematic diagrams 1.5, 1.5.1, 1.5.2, 1.5.3

Wing load $(W/S)_{scale}$ [t/m²]

0,8750
0,7875
0,7000
0,6125
0,5250
0,4375
0,3500
0,2625
0,1750
0,0875

87,5 175 262,5 350 437,5 525 612,5 700 787,5 875

Max TO-weight W_{max} [t]

Section 12

re: study phase 12

Problem and solution:

The transport capacity of a large passenger or transport aeroplane can be best assessed with the aid of a corresponding payload/range diagram.

In study phases 10 and 10a, two range equations are described in abbreviated and more detailed form, with the aid of which the following can be calculated:

- 1.) the range for maximum flying time at a specified flying height and
- 2.) the maximum range at a specified flying height.

The more detailed form of the equations is also suitable for producing the payload/range diagram for any transport aeroplane in use or for one of the configurations described in phase 3.

The more detailed form of the two range equations is as follows:

$$R_{Tmax} = (1 - W_E/W_{max} - W_{Pay}/W_{max}) \cdot (1/SFC) \cdot (V/\epsilon)_{Tmax} \cdot 3.6 \quad (135)$$

$$R_{max} = (1 - W_E/W_{max} - W_{Pay}/W_{max}) \cdot (1/SFC) \cdot (V/\epsilon)_{Rmax} \cdot 3.6 \quad (136)$$

If the ratio W_E/W_{max} is constant but the ratio W_{Pay}/W_{max} variable, these two equations produce two different payload/range diagrams, the first for maximum flying time and the second for maximum range.

The parameters $(1/SFC)$ and (V/ϵ) are constants, which vary per aeroplane or per configuration.

To produce the payload/range diagrams, the ratio W_{Pay}/W_{max} is changed in calculation steps from its maximum value to 0.

When calculating the payload/range diagrams, there are two further possibilities per diagram:

- a) the aeroplane weight W_{max} remains constant or
- b) the aeroplane weight W_{max} changes with reduction of the payload.

Case a) produces a longer range in relation to the payload, as a reduction of the payload is balanced out by fuel weight.

Case b) produces a shorter range in relation to the payload, as a reduction in payload is not balanced out by fuel weight, and there is therefore a lower aeroplane weight W_{max} in relation to the payload.

Section 12

The detailed form of the two equations is also suitable for calculating the ranges given in 1.) and 2.) in relation to the flying height.

The parameters (V/ϵ) are no longer treated as constants but as functions of the flying height.

$$(V/\epsilon)_{T_{\max}, h} = f(h) = (V/\epsilon)_{T_{\max}} \cdot (\rho/\rho_h)^{1/2} \quad (137)$$

$$(V/\epsilon)_{R_{\max}, h} = f(h) = (V/\epsilon)_{R_{\max}} \cdot (\rho/\rho_h)^{1/2} \quad (138)$$

With increasing flying height, the ranges given in 1.) and 2.) increase evenly, because the associated flying speed increases due to decreasing atmospheric density.

This continues in this way until the aeroplane drag increases due to the wave drag which occurs to such an extent that the increase in drag can no longer be compensated for by an increase in thrust.

An increase in thrust is possible, for example, when level flight takes place at mean thrust from two available engines, or when only one of two available engines is running in level flight at maximum thrust, while the second is idling.

Transport categories

The maximum value of the payload W_{Pay} in the equations 1.) and 2.) defines to which transport category an aeroplane or a configuration can be assigned.

It is useful to define the following categories thus:

$$\text{a) Medium-range transport } W_{\text{Pay}}/W_{\max} = 0.250 \quad (139)$$

$$\text{b) Short-range transport } W_{\text{Pay}}/W_{\max} = 0.375 \quad (140)$$

$$\text{c) Long-range transport } W_{\text{Pay}}/W_{\max} = 0.125 \quad (141)$$

The aeroplane weight $W_{\max}$ is constant.

Therefore, for each transport category there is a special payload/range diagram and a special dependency of range on flying height.

Section 12

Formulae for calculating the C_{D0} value with wave drag coefficient for transport aeroplanes:

$$C_{D0} = C_{D0, \text{without wave drag}} \cdot (1 + (M - 0.8) \cdot 40) \quad M = 0.8 \div 1.0 \quad (142)$$

$$\Delta C_{D0, \text{wave drag}} = (M - 0.8) \cdot 40 \cdot C_{D0, \text{without wave drag}} \quad (143)$$

Formulae for calculating engine thrust for transport aeroplanes:

$$F_{\text{mean, 1 engine}} = A_I \cdot \rho \cdot V^2 \quad \text{mean thrust of one engine} \quad (144)$$

$$F_{\text{max, 1 engine}} = 2 \cdot F_{\text{mean, 1 engine}} \quad \text{maximum thrust of one engine}$$

$$F_{\text{max, 2 engines}} = 4 \cdot F_{\text{mean, 2 engines}} \quad \text{maximum thrust of 2 engines} \quad (145)$$

Formula for calculating the wave drag coefficient of the C_{D0} value, which can be compensated for by reserve thrust:

$$\Delta C_{D0, \text{wave drag}} = 3 \cdot (A_I/S) = 3 \cdot C_{D0, \text{without wave drag}} \quad (146)$$

Section 12

Results:

For basic configuration 1 shown in phase 3, page 6, two payload/range diagrams were produced.

Fig. 1 on page 5 shows the maximum ranges, whereas fig. 2 on page 6 shows the ranges for maximum flying time.

The individual figures contain the payload/range diagrams for the three transport categories a, b and c.

The diagrams apply to a flying height $h = 7$ km.

In addition, two diagrams were produced for the relation between ranges and flying height for the same configuration.

Fig. 3 on page 7 shows the relation between the maximum ranges and the flying height, whereas fig. 4 on page 8 shows the relation between the ranges with maximum flying time and flying height.

For a flying height $h = 7$ km, the diagram of the maximum ranges is based on a Mach number of $M = 0.705$ and the diagram of the ranges with maximum flying time on a Mach number of $M = 0.536$.

In the diagram on page 9 for the basic configuration 1 shown in phase 3, page 6, the C_{D0} value of the overall aeroplane is shown in relation to the Mach number of up to $M = 1.0$.

The diagram on page 10 shows the dependency of the maximum ranges and ranges for maximum flying time on flying height and Mach number.

The diagram contains the thrust limit which based on the equations on page 3 for configuration 1 is $M = 0.875$.

Three realistic mission profiles are shown on page 11 for basis configuration 1.

Each profile consists of take-off, climb, level flight, descent and landing.

One profile corresponds to flight with maximum flying time ($M = 0.536$), the other two profiles to flight with maximum range ($M = 0.705$).

Take-off and landing distances as well as climb and descent are the same for all mission profiles.

For scaling of configuration 1, see section 11, it is useful to know how large the dimensions of the scaled cubic cargo compartment elements is.

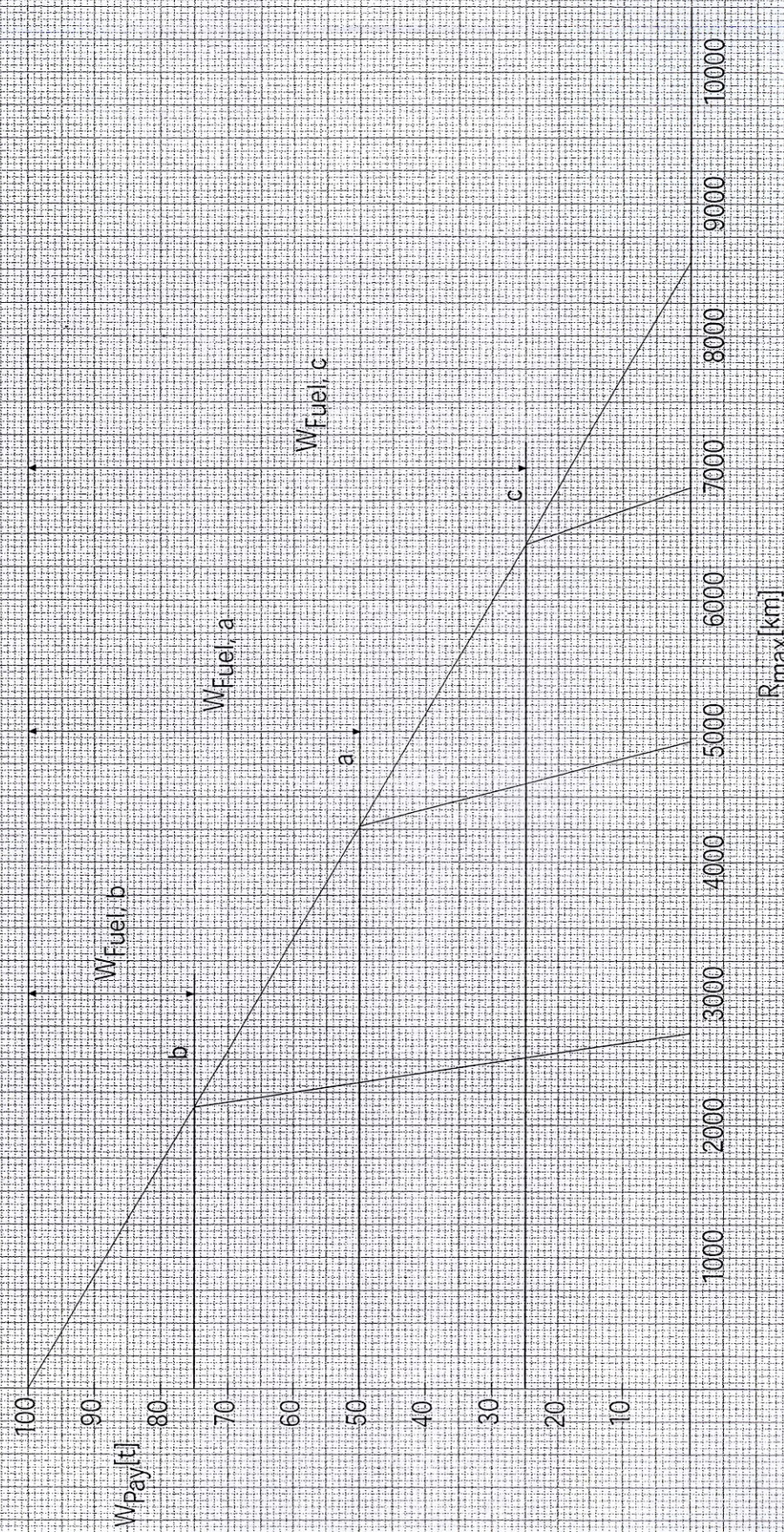
Page 12 shows the following scaling cargo compartment element function:

$$b = h = f(W_{\max}) \quad (147)$$

Section 12

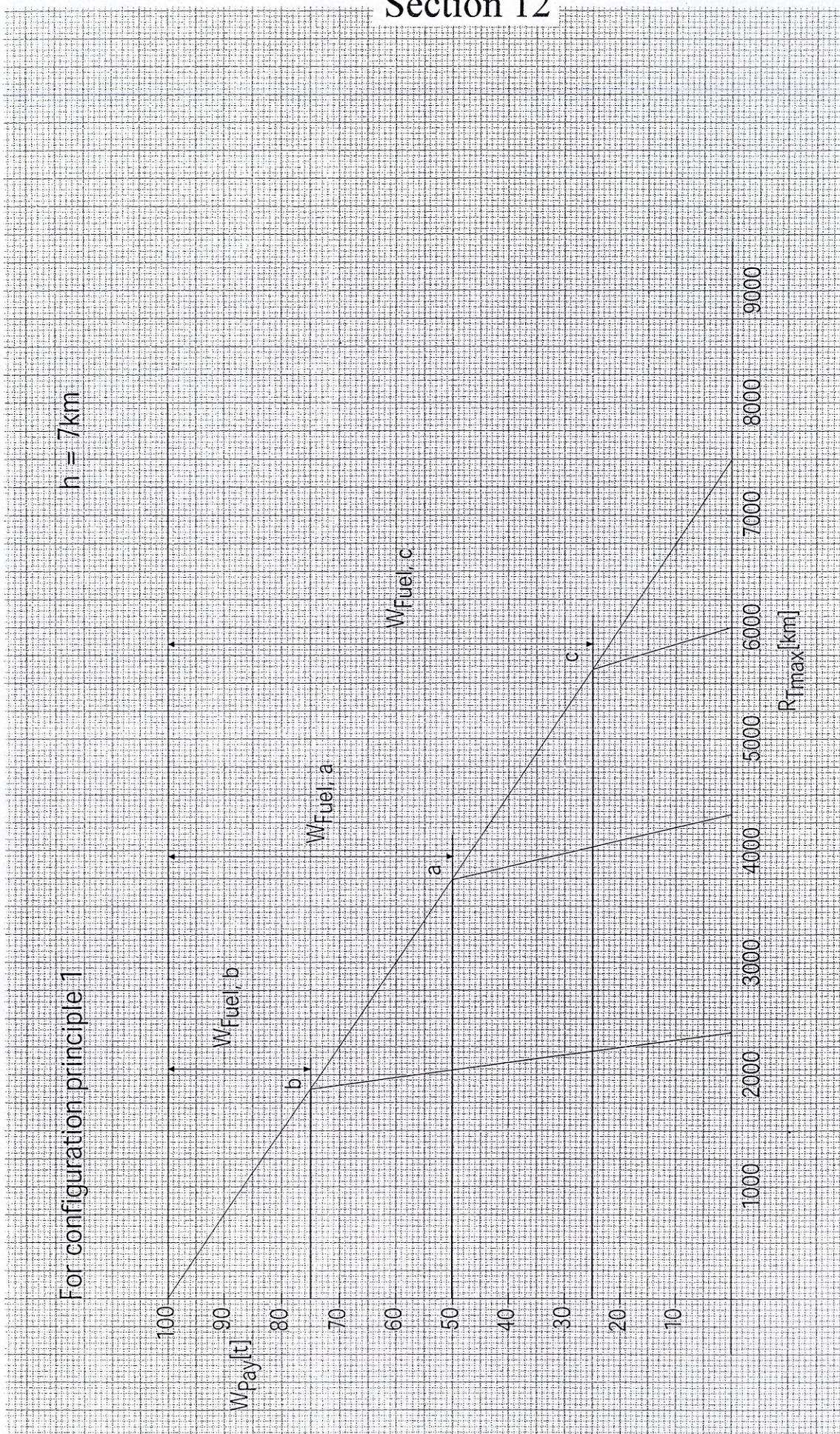
For configuration principle 1

$h = 7\text{km}$



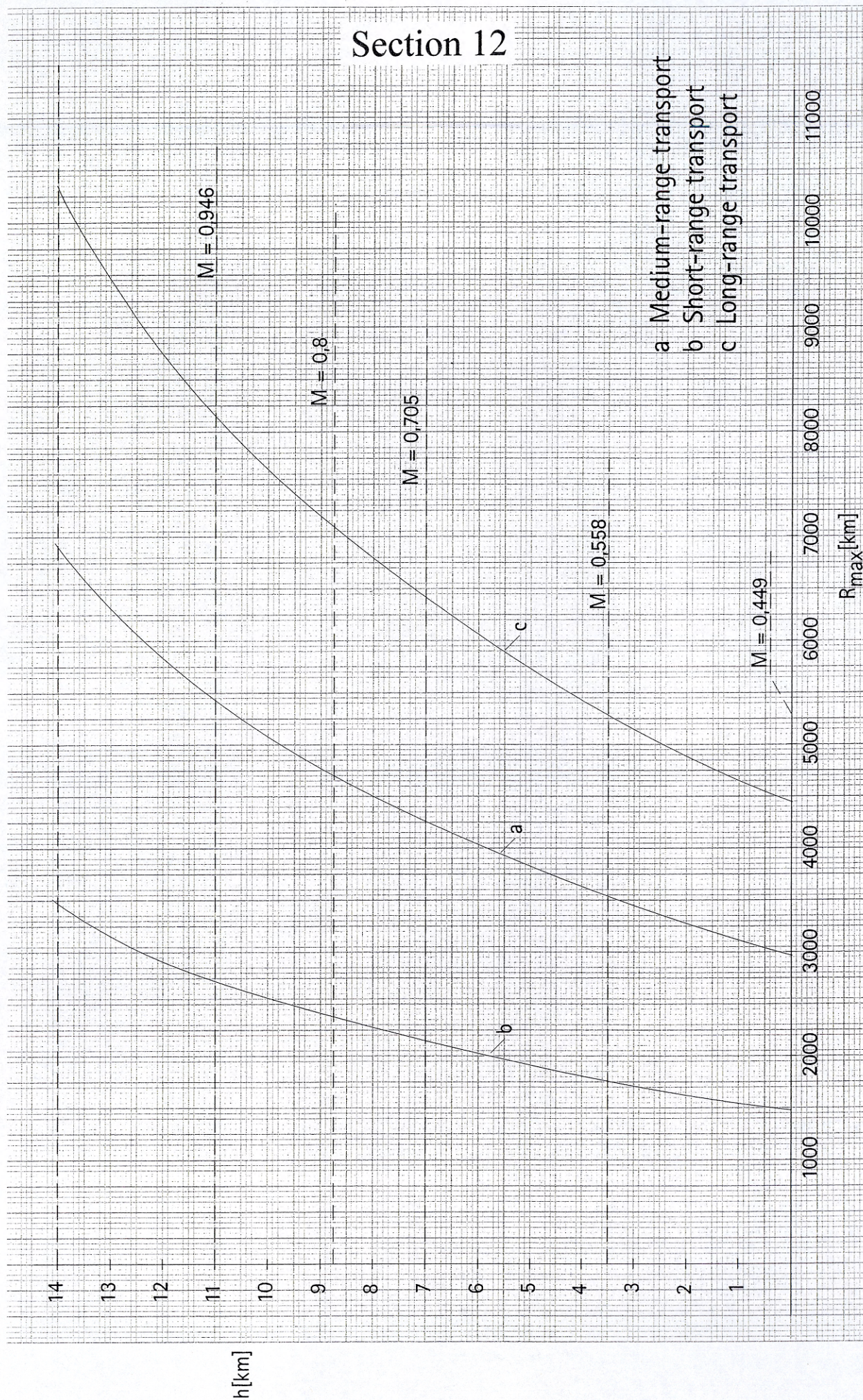
- a Medium-range transport
- b Short-range transport
- c Long-range transport

Section 12



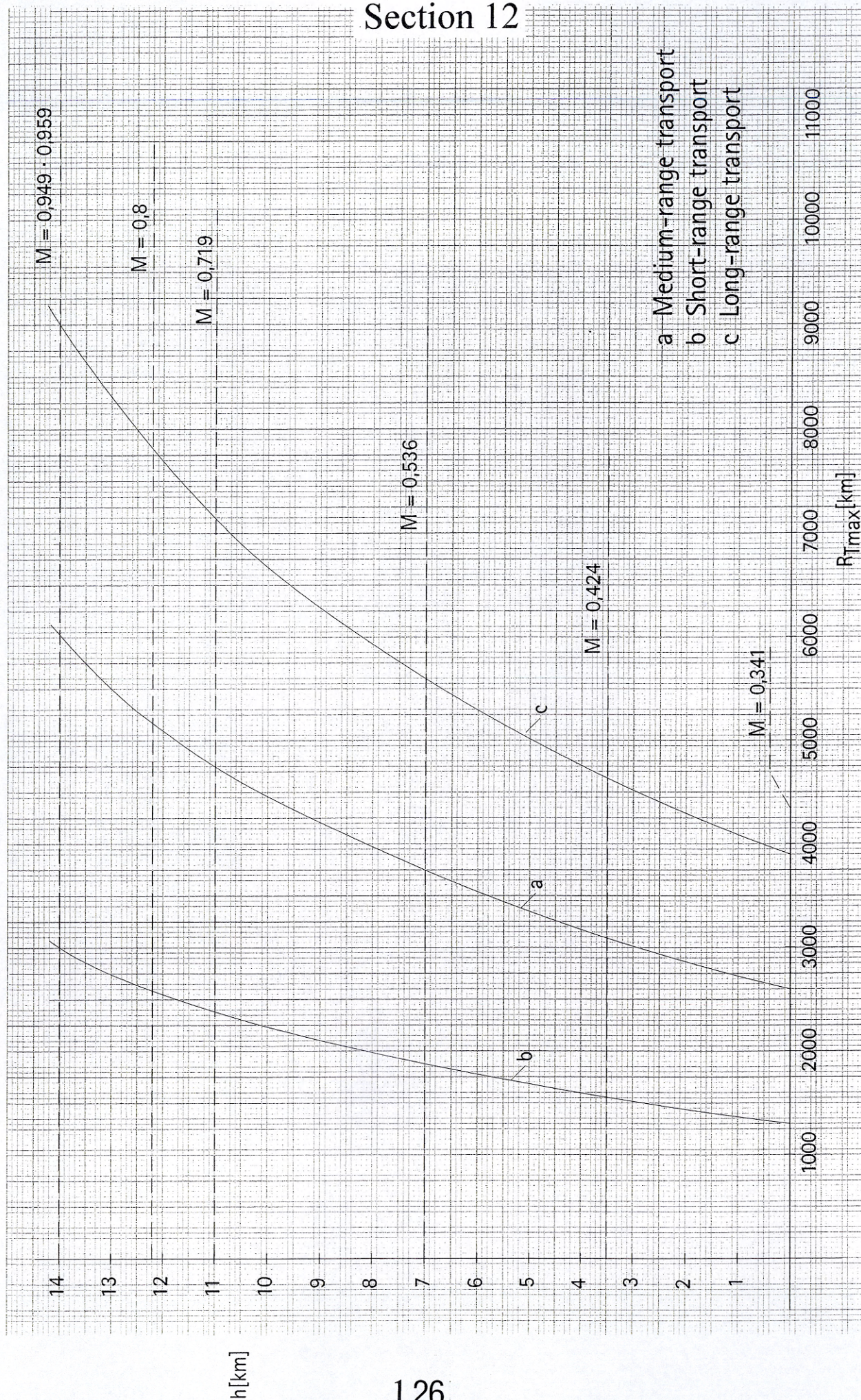
- a Medium-range transport
- b Short-range transport
- c Long-range transport

For configuration principle 1



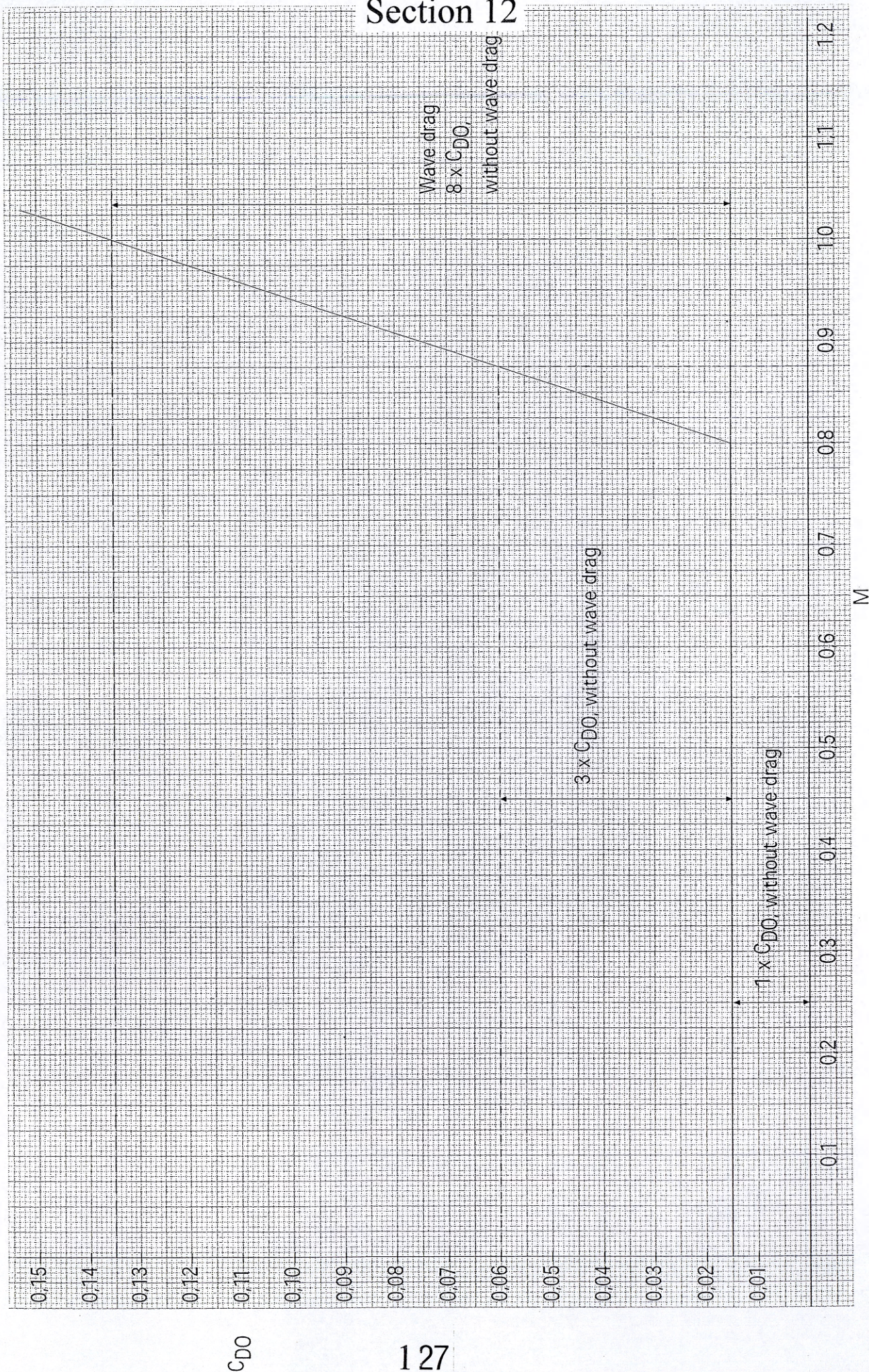
For configuration principle 1

Section 12



For configuration principle 1

Section 12

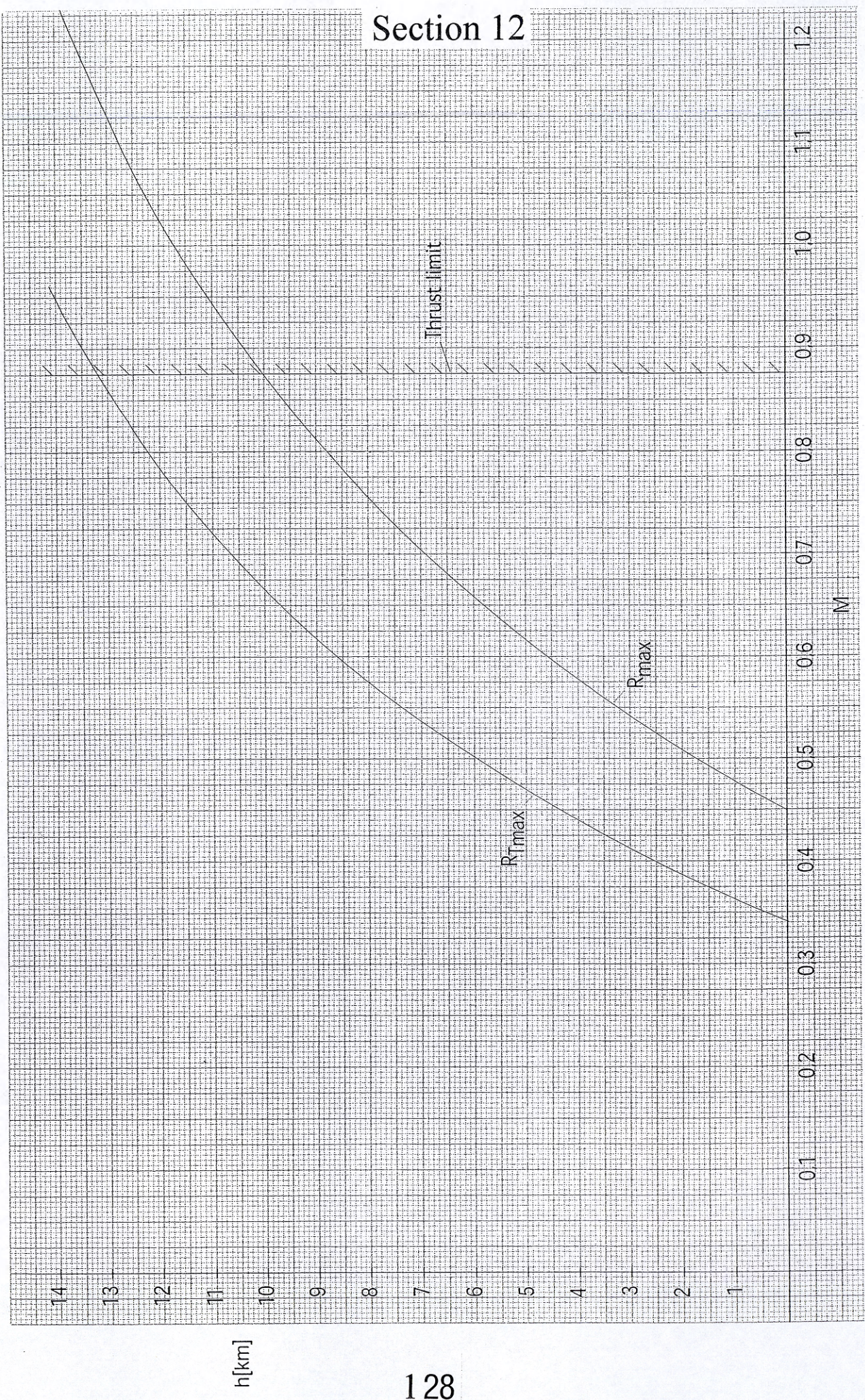


C_{D0}

127

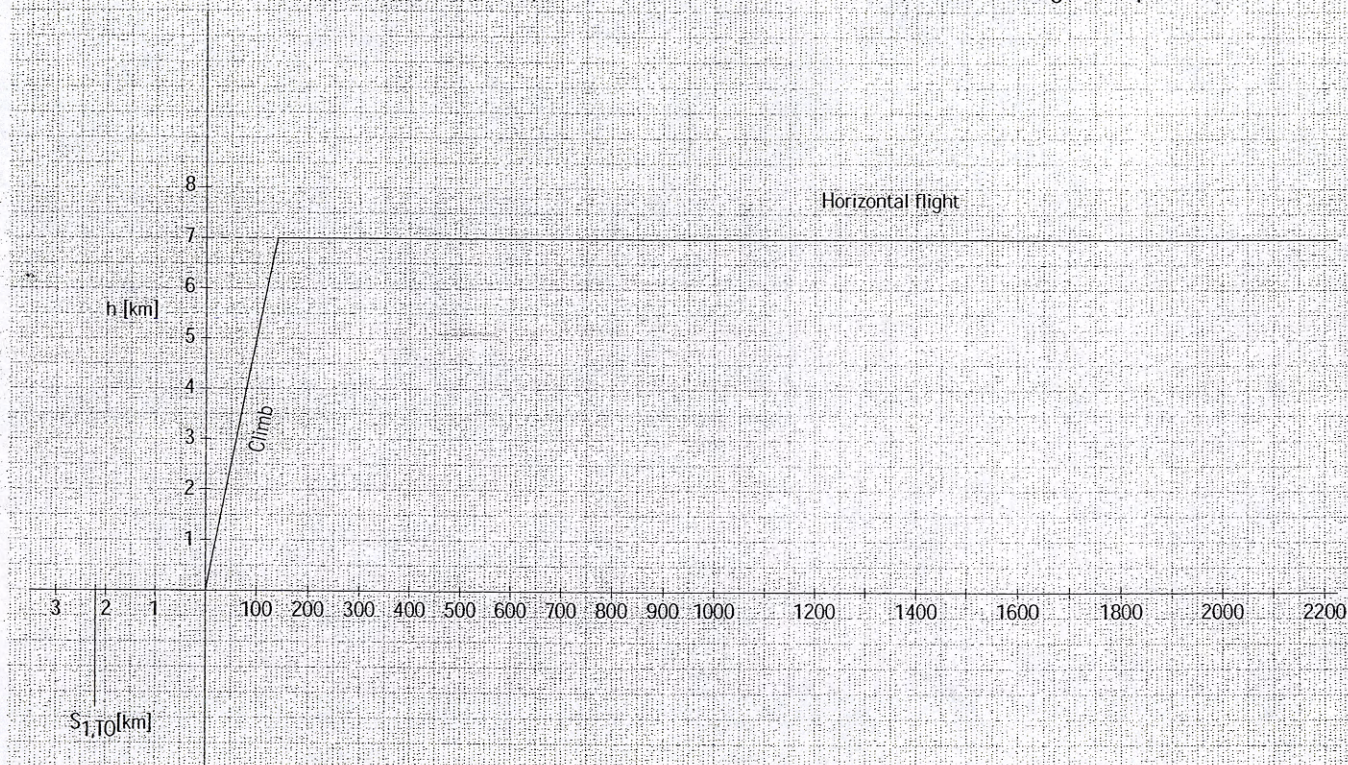
Section 12

For configuration principle 1

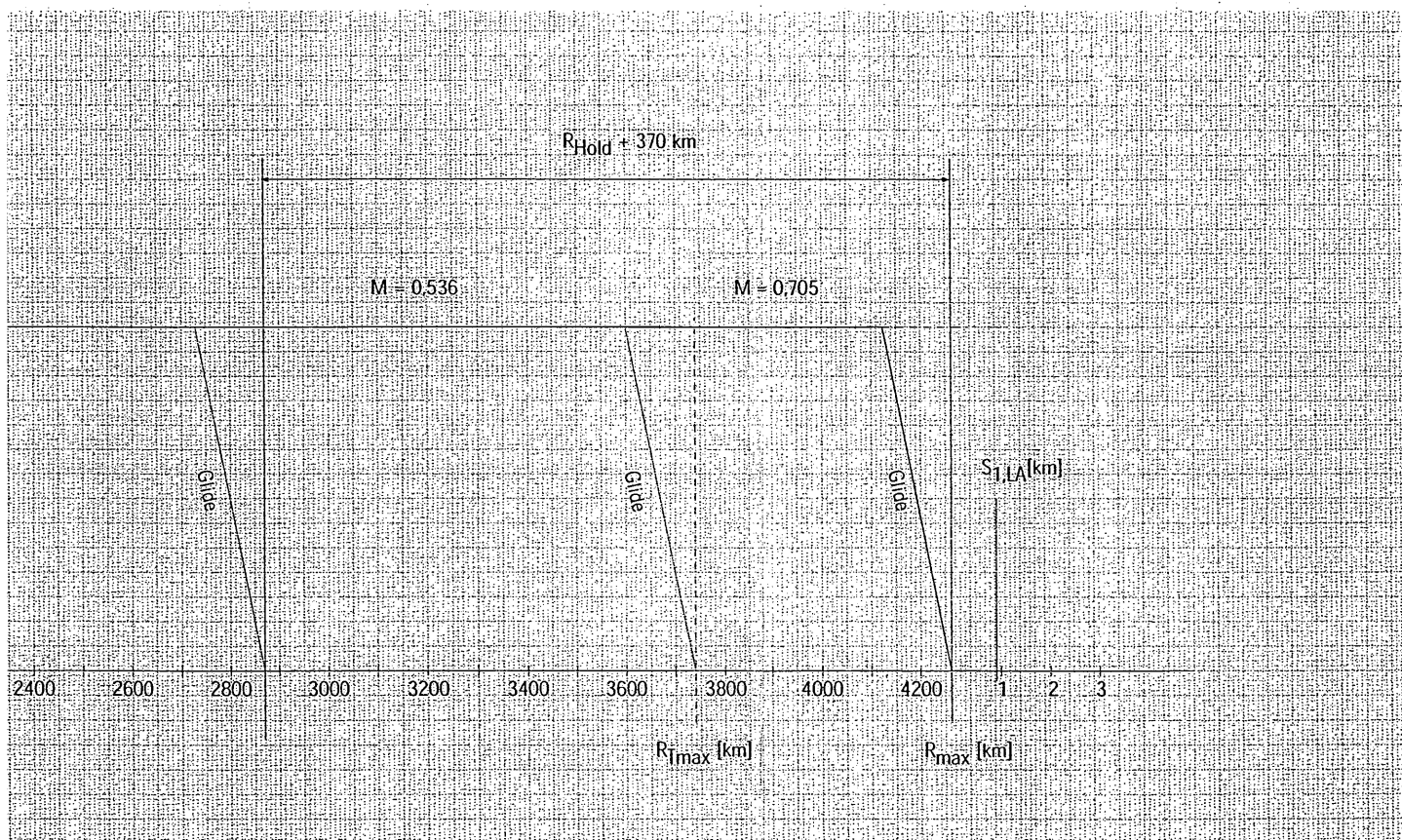


For configuration principle 1

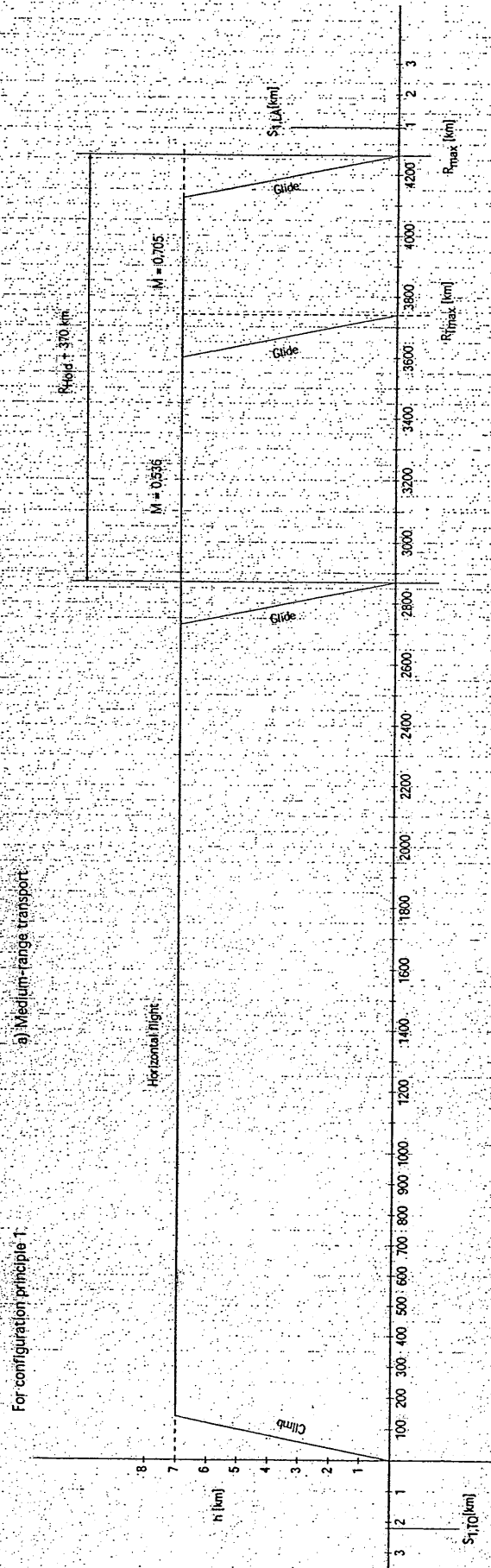
a) Medium-range transport



Section 12



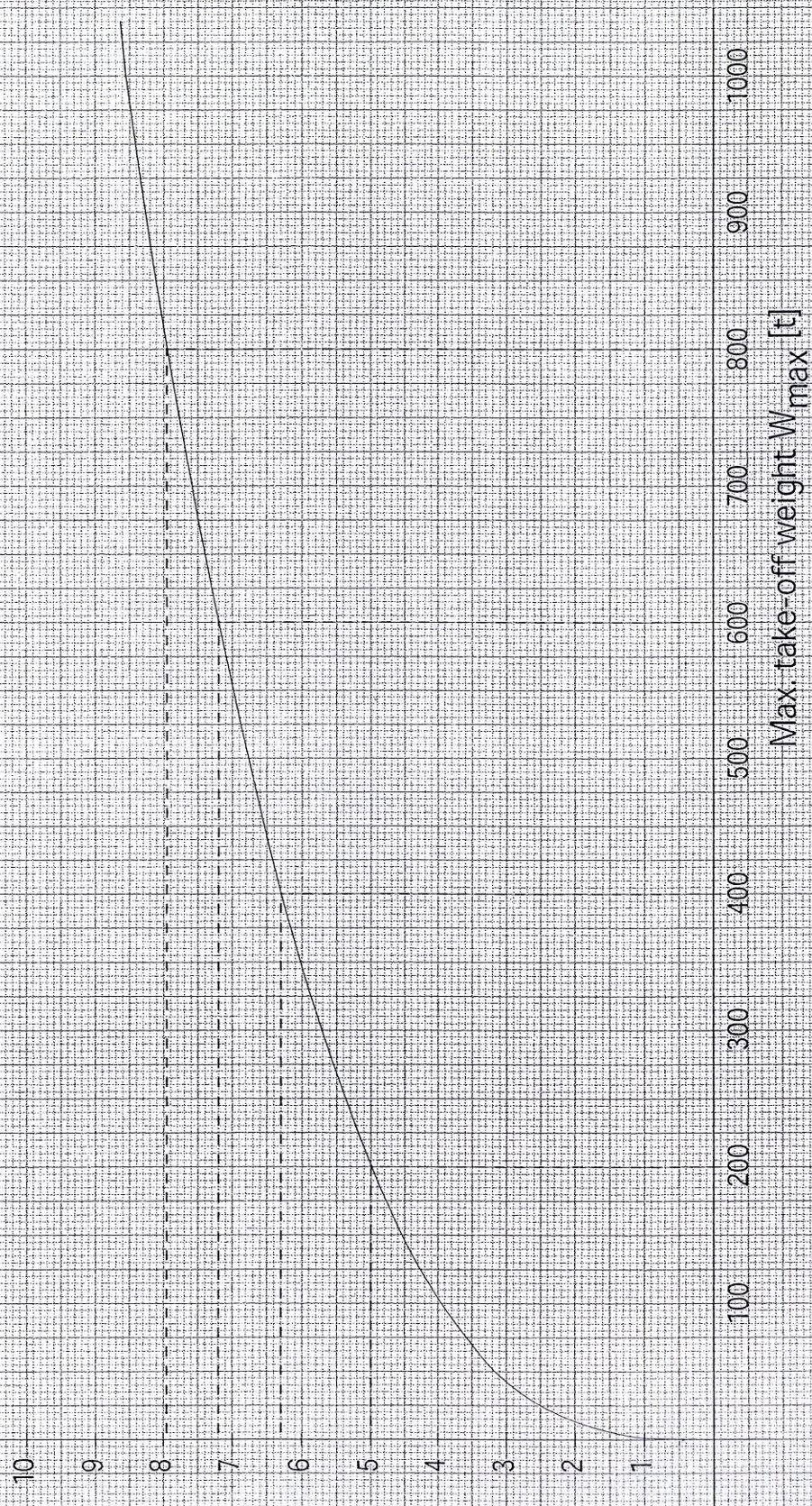
Section 12



Section 12

For configuration principle 1, 1.1, 1.2, 1.3

Hold – Element dimension b [m] or h [m]



Section 13

re. study phase 13

Problem and solution:

In study phases 3 and 4, 11 transport aeroplane configurations were developed according to the new design method, of which the configurations 1, 2, 4 and 5 are referred to as basic configurations in study phase 8.

To be able to compare transport aeroplane configurations, 5 comparative quantities were defined in study phase 8.

Of these quantities, the flying performance with regard to range in connection with the payload is of particular interest.

Study phase 8 shows a comparative table for configurations 1, 2, 4 and 5, which contains all intermediate quantities necessary for calculating the ranges and their values as well as the main ranges R_{Tmax} and R_{max} and their values.

The ranges in the comparative table were determined with the aid of the formulae (76) to (80) described in study phase 8 and a calculator.

Apart from in a comparative table, these ranges can also be displayed in a comparative diagram.

The ranges R_{Tmax} and R_{max} can be calculated for different transport categories (see study phase 12), but to see the ratios it is sufficient to only produce the diagram for medium range transport and then enter the ferry ranges $R_{Tmax, Ferry}$ and $R_{max, Ferry}$.

Results:

The range diagram on page 3 was created with the aid of the PC program KONFPRINZ1B, which uses the formulae (76) to (80), and is based on the following assumptions for the basic configurations:

$W_{max} = 200 \text{ t}$	Configuration 1, 2 and 5
$W_{max} = 250 \text{ t}$	Configuration 4
$W_E/W_{max} = 0.5$	
$W_{Pay}/W_{max} = 0.25$	(for medium range transport)
$SFC = 0.8 \text{ lb}/(\text{lb} \cdot \text{h})$	
$k_R = 0.3125 \text{ lb} \cdot \text{h}/\text{lb}$	

The ranges R_{Tmax} and R_{max} differ by the same constant factor with all configurations:

$$R_{max} = (27/16)^{1/4} \cdot R_{Tmax} = 1.13975 \cdot R_{Tmax} \quad (148)$$

If one of the two ranges is known, the other can be stated immediately.

Section 13

The condition for this is that the quantity k_R in the range formulae (76) and (77) has the same value for all configurations.

The quantity k_R changes according to the transport category.

$k_R = 0.3125 \text{ lbf} \cdot \text{h/lb}$	Medium range transport
$k_R = 0.15625 \text{ lbf} \cdot \text{h/lb}$	Short range transport
$k_R = 0.46875 \text{ lbf} \cdot \text{h/lb}$	Long range transport
$k_{R, \text{Ferry}} = 0.625 \text{ lbf} \cdot \text{h/lb}$	Ferry flight

For configuration 1 the PC program produces the following main mission data:

Medium range transport

$h = 7 \text{ km}$

$R_{\max} = 4264 \text{ km}$; $M = 0.705$

$R_{T\max} = 3741 \text{ km}$; $M = 0.536$

$h = 11 \text{ km}$

$R_{\max} = 5427 \text{ km}$; $M = 0.946$ (cannot be flown because M becomes too large)

$R_{T\max} = 4761 \text{ km}$; $M = 0.719$

The following rules can also be derived from the formulae (76) to (80):

The percentage difference between $R_{\max}$ and $R_{T\max}$ is independent of the flying height!

The percentage difference between $R_{\max}$ and $R_{T\max}$ is independent of the transport category!

The percentage difference between $R_{\max}$ and $R_{T\max}$ also applies to the ferry flight!

The following can be read off from the diagram on page 3:

Compared to configuration 1, configuration 5 has a significant advantage in terms of range.

The difference is + 14.6 %.

Compared to configuration 1, configuration 4 has no notable advantage or disadvantage in terms of range.

The difference is only -1.5 %.

Compared to configuration 1, configuration 2 has a considerable disadvantage in terms of range.

The difference is -8.9 %.

a) Medium range transport

Section 13

Configuration principle

$h = 7 \text{ km}$

5

4

(3)

2

1

R_{Tmax}

R_{max}

$R_{Ferry, theor.}$

R_{max}

T_{max}

$R \text{ [km]}$

1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000

CHAPTER 5

Validation of methodology

Validation of methodology

Validation of methodology

Study phase 5 shows a flowchart of the new design methodology.

This shows that the following can be calculated based on associated mathematical equations:

- a) flight performances
- b) aeroplane dimensions
- c) engine dimensions

There are three ways of working with these equations:

- 1.) calculating results for a), b) and c) with appropriate input data and determining a new, theoretical aeroplane configuration;
- 2.) calculating the results for a), b) and c) belonging to a constructed aeroplane with known input data for the equations and comparing the resulting aeroplane configuration with the actual configuration;
- 3.) calculating the results for a) belonging to a constructed aeroplane with known input data and comparing the resulting range with that specified by the aeroplane manufacturer.

For point 2.) it is expedient to start with a theoretical aeroplane configuration calculated in accordance with 1.) and then recalculate it with the aid of the known input data – see Appendix A, File 2, document 45.

For point 3.) one has to depend on reliable information of the aeroplane manufacturer for take-off weight, dead weight, payload and fuel reserves of the aeroplane and specific consumption of the engines.

The results of points 2.) and 3.) enable a statement to be made on the validation or quality of the design methodology.

Document 45 contains the relevant results for point 2.).

These results were calculated using the theoretical basic configuration 1 of study phase 3 or the associated data.

The relevant results for point 3.) are given in study phases 10 and 10a.

These results are based on more exact values for the quotients flying speed/drag-lift ratio – see study phase 10.

Validation of methodology

Deviation of the aeroplane configuration calculated in accordance with point 2.) from the actual configuration

Surface load: -12.3 % to + 3.1 %

Wingspan: -1.5 % to + 6.8 %

Fuselage length: -3.3 % to + (13.0 %)

Fuselage width: + 3.4 % to + (28.6 %)

Engine inlet diameter: - 9.2 % to - 3.0 %

The new design methodology is therefore suitable for point 2.), as great deviations, values in (), only result from special design features of the actual transport or passenger aeroplane.

Deviation of the range calculated in accordance with point 3.) from that specified by the aeroplane manufacturer

Flight conditions

maximum take-off weight, maximum payload

Range, minus reserves: - 6.9 % to + 12.5 %

Flight conditions

maximum take-off weight, no payload

mean take-off weight, no payload

Ferry range, no reserves: - 3.1 % to + 5.7 %

The new design methodology is therefore also suitable for point 3.).

CHAPTER 6

Discussion of results

Discussion of results

Discussion of results

Each section of study phases 1 to 13 describes the associated interim results.

To obtain an overall overview, it is expedient to summarise the main results again.

Study phases 1 to 4 describe in detail how the method works based on calculations and associated configuration designs.

The result of sections 1 and 2 is a design base with the aid of which the maximum weight and size of an initial configuration is formed to produce several different configurations:

- maximum take-off weight 200 t
- payload for medium-range transport 50 t
- aeroplane volume 1000 m³
- cargo volume 250 m³

This includes the approximate flying performance:

- Range 3750 km (flying time is maximum)
- Flying speed 600 kph
- Flying height 7 km
- Flying time 6.25 hrs

The result of study phases 3 is 5 basic configurations which are formed with the aid of an initial configuration:

- aeroplane with rear elevator unit (1)
- aeroplane with front elevator unit (2)
- aeroplane with front and rear elevator unit (3)
- aeroplane with tandem arrangement of wings (4)
- aeroplane without the usual elevator unit, only wing (5)

The 5 configurations have the same size wing and elevator unit areas (if the latter exist).

Configurations (1), (2), (3) and (5) have the same fuselage length but with (4) the total hold is extended towards the front by one hold element for reasons of centre of gravity and weight.

Discussion of results

As a result of the different wing and elevator unit arrangement on the overall hold, the individual configurations have different flying performances.

Results: configuration (1)
maximum range 4264 km
flying speed $M = 0.705$
flying height 7 km

Compared with configuration (1), the following range differences result for the other configurations:

configuration (2) - 8.9 %
configuration (3) was not considered
configuration (4) - 1.5 %
configuration (5) +14.6 %

The result of study phase 4 is 6 extended configurations, which are also formed with the aid of the initial configuration (1):

aeroplane with three equal size wings in tandem arrangement (6)
aeroplane with rhombus wing arrangement (7)
aeroplane with rear elevator unit and double fuselage (8)
aeroplane with front elevator unit and double fuselage (9)
aeroplane with two equal size wings in tandem arrangement and double fuselage (10)
aeroplane with front elevator unit and double fuselage (11)

Configuration extensions:

Apart from the main fuselage, wing and elevator unit areas, configurations (8), (9), (10) and (11) have smaller outer fuselages to carry or support the elevator units.

Configuration (6) has 2 more hold elements than configuration (1) for reasons of centre of gravity and weight.

Configuration (10) has 1 more hold element than configuration (1) for reasons of centre of gravity and weight.

Configuration (7) has wing-tip elements to reinforce the rhomboid wing arrangement.

Configurations (6) and (10) have two additional engines on the front wing(s).

These are necessary because the maximum take-off weight is greater here.

Discussion of results

Study phases 6 and 7 describe aerodynamic correlations and the engines for large transport or passenger aeroplanes.

The result of study phase 6 is a variable aeroplane polar in general and adapted mathematical form.

The constants in the polar equations were adapted to configuration (1) and have the following values:

Coefficient of the zero resistance $C_{D0} = 0.015$

Factor of the induced resistance $k = 0.0415$

The adapted polar is a square polar which runs symmetrically to the x-axis without wing flap deflection, but is offset upwards or downwards in the direction of the y-axis with positive or negative wing flap deflection.

The polar symmetrical to the x-axis has three very important flight points:

1. Point for best gliding $(C_D/C_L)_{\min}$
2. Point for lowest descent $(C_D^2/C_L^3)_{\min}$
3. Point for greatest range $(C_D^2/C_L)_{\min}$

The following reciprocal variables for these polar points result for configuration (1):

1. $C_D/C_L = 0.05$
2. $C_D/C_L = 0.0577$
3. $C_D/C_L = 0.0577$

The reciprocal variables of 2. and 3. have the same value.

The adapted square polar includes the straight line lift coefficient as a function of the geometric angle of attack without and with maximum positive wing flap deflection.

For configuration (1):

Increase in lift of the wing: $(dC_L/d\alpha)_s = 5.0$

Lift coefficient with maximum positive wing flap deflection of 60°: $C_{L\max} = 2.04$

Geometric angle of attack at $C_{L\max}$: $\alpha = 23.3^\circ$

Discussion of results

The first result of study phase 7 is the answer to what engines or drives are suitable for large transport or passenger aeroplanes.

Suitable engines:

1. Propeller piston engine (PPE)
2. Propeller turbojet engines (PTJ or turboprops)
3. Twin-circuit turbofan engines (TF or turbofans)
4. Turbojet engines (TJ or turbojets)

Mean specific fuel consumption SFC:

PPE 0.23 kg/(HP · hr)

PTJ 0.25 kg/(HP · hr)

TF 0.7 kg/(kp · hr)

TJ 1.0 kg/(kp · hr)

The second result is the ratio of the external dimensions of these engines which is a function of the main flow ratio and bypass ratio of the individual drives.

Ratio of the external dimensions l/d_f :

PPE 1.0

PTJ 2.1 (bypass ratio > 10)

TF 2.21 (bypass ratio = 6)

TJ 2.9 (bypass ratio = 0)

The third result is the engine diameter.

The different drives have the same diameter for the specified mean thrust.

Result for configuration (1):

TJ $d_f = 2.8 \text{ m}$; $l = 8.12 \text{ m}$

With mean thrust, the speed of the jet on engine outlet is $2 \cdot V$ and with maximum thrust $3 \cdot V$.

Discussion of results

Study phases 8, 10 and 10a describe calculations and associated flying performances for the basic configurations and the 10 constructed transport or passenger aeroplanes.

The result of study phase 8 is fundamental ranges and associated flying speeds for the basic configurations 1, 2, 4 and 5.

The following ranges and speeds were calculated:

- range with maximum flying time R_{Tmax}
speed with maximum flying time V_{Tmax}
- maximum range R_{max}
speed with maximum range V_{Rmax}

The results of the individual configurations and the associated interim results as well as the C_{D0} - and k -data are given in the results table of study phase 8.

Range results for flying height 7 km:

Configuration 1: $R_{Tmax} = 3750$ km
 $R_{max} = 4274.05$ km

Configuration 2: $R_{Tmax, 1}$ and $R_{max, 1}$ - 8.9 %

Configuration 4: $R_{Tmax, 1}$ and $R_{max, 1}$ - 1.9 %

Configuration 5: $R_{Tmax, 1}$ and $R_{max, 1}$ + 15.3 %

Speed results for flying height 7 km:

Configuration 1: $V_{Tmax} = 166.33$ m/s
 $V_{Rmax} = 218.91$ m/s

Configuration 2: $V_{Tmax, 1}$ and $V_{Rmax, 1}$ - 3.1 %

Configuration 4: $V_{Tmax, 1}$ and $V_{Rmax, 1}$ - 15.0 %

Configuration 5: $V_{Tmax, 1}$ and $V_{Rmax, 1}$ + 4.9 %

Index 1 means : from configuration 1

Discussion of results

The result of study phases 10 and 10a is fundamental ranges and associated flying speeds for 10 constructed transport or passenger aeroplanes.

The following ranges and flying speeds were calculated:

- maximum range with maximum payload $R_{\max}$
speed $V_{R_{\max}}$ with $R_{\max}$
- theoretical maximum range without payload $R_{\max, \text{Ferry}}$
- range with maximum fuel and payload $R_{\max, \text{Fuel}}$
- range with maximum fuel without payload R_{Ferry}

The resulting values for the individual constructed transport or passenger aeroplanes are given in the results tables of study phases 10 and 10a.

These results were compared with the data given by the aeroplane manufacturer and are used to assess the validity of the new range formulae used.

Maximum range deviations:

$R_{\max}$: - 10.5 % to + 12.5 %	Lockheed L-100 / Airbus A300B
$R_{\max, \text{Ferry}}$: - 3.1 % to + 89.1 %	Lockheed C-5A / Airbus A300B
$R_{\max, \text{Fuel}}$: - 0.5 % to + 2.9 %	Boeing 737-200C / Lockheed L-1011
R_{Ferry} : - 3.1 % to 0 %	Lockheed C-5A / various aeroplanes

Maximum flying speed deviations:

$V_{R_{\max}}$: - 11.7 % to + 6.4 %	Airbus A300B / M.D. DC-10, Srs 10
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Comments:

The great deviation in $R_{\max, \text{Ferry}}$ is due to the fact that here the maximum take-off weight is assumed but no payload.

The flying speed deviations were calculated subsequently.

Discussion of results

In study phase 11, the scaling of the basic configurations is described and in study phase 12, 2 basic versions of the payload/range diagrams of basic configuration 1 are described.

The results of study phase 11 are:

- 1.) 2 scaling factor functions for scaling of the basic configurations 1, 2, 4 and 5 to any maximum take-off weight from 200 t to 1000 t
- 2.) 2 scaling factor functions for scaling of one lengthened and one shortened basic configuration 1 to any maximum take-off weight from 225 t to 900 t or 175 t to 700 t respectively
- 3.) 2 scaling wing load functions of 1.) for scaling of the basic configurations 1, 2, 4 and 5 to any maximum take-off weight from 200 t to 1000 t
- 4.) 2 scaling wing load functions of 2.) for scaling of one lengthened and one shortened basic configuration 1 to any maximum take-off weight from 225 t to 900 t or 175 t to 700 t respectively

From the function of 1.), the following scaling factors are obtained k_{scale} :

Configurations 1, 2 and 5	Configuration 4
200 t : 1.0	250 t : 1.0
400 t : 1.26	500 t : 1.26
600 t : 1.44	750 t : 1.44
800 t : 1.59	1000 t : 1.59

From the function of 2.), the following scaling factors are obtained k_{scale} :

Configuration 1 lengthened	Configuration 1 shortened
225 t : 1.0	175 t : 1.0
450 t : 1.26	350 t : 1.26
675 t : 1.44	525 t : 1.44
900 t : 1.59	700 t : 1.59

From the function of 3.), the following scaling surface loads are obtained $(W/S)_{scale}$:

Configurations 1, 2 and 5	Configuration 4
200 t : 0.5	250 t : 0.625
400 t : 0.63	500 t : 0.788
600 t : 0.72	750 t : 0.900
800 t : 0.795	1000 t : 0.994

From the function of 4.), the following scaling surface loads are obtained $(W/S)_{scale}$:

Configuration 1 lengthened	Configuration 1 shortened
225 t : 0.563	175 t : 0.438
450 t : 0.709	350 t : 0.551
675 t : 0.810	525 t : 0.630
900 t : 0.894	700 t : 0.696

Discussion of results

One main result of study phase 12 is 2 versions of the payload/range diagrams for basic configuration 1.

Flying height 7 km :

- a) $W_{\text{Pay}} = f (R_{\text{max}})$ medium range transport
- b) $W_{\text{Pay}} = f (R_{\text{max}})$ short range transport
- c) $W_{\text{Pay}} = f (R_{\text{max}})$ long range transport

Flying height 7 km:

- a) $W_{\text{Pay}} = f (R_{\text{Tmax}})$ medium range transport
- b) $W_{\text{Pay}} = f (R_{\text{Tmax}})$ short range transport
- c) $W_{\text{Pay}} = f (R_{\text{Tmax}})$ long range transport

The 2 versions of the payload/range diagrams also contain 2 versions of the flying height/range diagrams with the curves:

- a) $h = f (R_{\text{max}})$ medium range transport
- b) $h = f (R_{\text{max}})$ short range transport
- c) $h = f (R_{\text{max}})$ long range transport

- a) $h = f (R_{\text{Tmax}})$ medium range transport
- b) $h = f (R_{\text{Tmax}})$ short range transport
- c) $h = f (R_{\text{Tmax}})$ long range transport

The associated flight Mach numbers are entered in these diagrams as horizontal dotted lines.

The flight Mach numbers are different in the individual diagram versions for R_{max} and R_{Tmax} .

The ranges given in the flying height/range diagrams at $h = 7$ km correspond to those of the payload/range diagrams.

Another result of study phase 12 is the diagrams for zero resistance as a function of the flight Mach number and the flying height/flight Mach number diagram for the ranges R_{max} and R_{Tmax} .

Both diagrams only apply to basic configuration 1.

The flying height/ flight Mach numbers diagram also contains the flight Mach numbers limit, which is defined by the maximum thrust 2 engines and the wave resistance for configuration 1.

The maximum achievable flight Mach number is:

$$h = 13.2 \text{ km}$$
$$M = 0.875 \text{ for } R_{\text{Tmax}}$$

$$h = 10.0 \text{ km}$$
$$M = 0.875 \text{ for } R_{\text{max}}$$

Discussion of results

In study phase 13, particularly interesting results of study phase 8 are compared to show which of the basic configurations 1, 2, 4 and 5 is the best.

The result of study phase 13 is a range diagram for the basic configurations, in which the ranges R_{Tmax} , R_{max} and $R_{Ferry, theor.}$ are entered.

This diagram only applies to the flying height of 7 km and allows a clear comparison of the relevant ranges for the basic configurations 1, 2, 4 and 5.

The following range data are entered in the diagram:

Medium-range transport:

Configuration 1:	$R_{Tmax} = 3740.75 \text{ km}$	$R_{max} = 4263.53 \text{ km}$
Configuration 2:	$R_{Tmax} = 3408.16 \text{ km}$	$R_{max} = 3884.47 \text{ km}$
Configuration 3:	$R_{Tmax} = \quad / \quad$	$R_{max} = \quad / \quad$
Configuration 4:	$R_{Tmax} = 3685.11 \text{ km}$	$R_{max} = 4200.12 \text{ km}$
Configuration 5:	$R_{Tmax} = 4286.81 \text{ km}$	$R_{max} = 4885.90 \text{ km}$

Ferry flight:

Configuration 1:	$R_{Tmax, Ferry, theor.} = 7481.50 \text{ km}$
	$R_{max, Ferry, theor.} = 8527.04 \text{ km}$

The range differences of configurations 2, 4 and 5 compared with configuration 1 are also given in per cent in the discussion of results of phases 1 and 2.

Configuration 5 has the biggest range R_{max} of + 14.6 % compared with configuration 1.

The ranges R_{Tmax} and R_{max} differ for all configurations by a fixed factor of 1.13975 .

This also applies to the ranges $R_{Tmax, Ferry, theor.}$ and $R_{max, Ferry, theor.}$.

The ranges R_{Tmax} and R_{max} differ from the ranges $R_{Tmax, Ferry, theor.}$ and $R_{max, Ferry, theor.}$ by a factor of 2, as the latter are flown with twice the amount of fuel.

In addition to configuration 1, this also applies to configurations 2, 4 and 5.

Discussion of results

Study phases 5 and 9 mark special points in the overall study phases.

In study phase 5, important findings thus far obtained, are presented in the form of a design method, whereas study phase 9 lists study or research objectives to be achieved.

The result of study phase 5 is a flow chart of the new design method.

It consists of 7 work blocks to be run through in sequence if the method is to be used successfully.

One special feature of the flow chart is the influence diagram, which shows the dependence of the design parameters of the transport aeroplane such as flight performances, aeroplane size and engine size on input parameters such as flying weight, lift, resistance and engine thrust.

The result of study phase 9 is 8 study objectives, of which a very important one is the definition of a range for the take-off weight of the transport aeroplanes to be studied.

For this, the diagram of maximum surface load was produced as a function of the maximum take-off weight $(W/S)_{\max} = f(W_{\max})$ for large transport and passenger aeroplanes built up to now.

In study phase 9, the so-called PhD OBJECTIVES were also defined by the university, which are listed by number in introduction on page 12.

CHAPTER 7

Application of the design methodology to 5 configurations

Application of the design methodology

Limits for the application

1. Aeroplane category
Transport aeroplane or passenger aeroplane
civil or military
2. Aeroplane weights
Maximum take-off weight: 200 t to 800 t
Mean payload: 50 t to 200 t
Mean specific weight of hold:
Transport aeroplane 0.2 t/m^3
Passenger aeroplane 0.25 t/m^3
3. Aeroplane configurations, possible
Aeroplanes with one main fuselage
Aeroplane with rear elevator unit (1)
Aeroplane with front elevator unit (2)
Aeroplane with front and rear elevator unit (3)
Aeroplane with tandem arrangement of wings (4)
Aeroplane without the usual elevator unit, wing only (5)
Aeroplane with tandem arrangement of three wings of same size (6)
4. Flight performance for medium range transport, reference values
Flying weight: 200 t
Flying height 7 km
Range: 3745 km to 4270 km
Mach operating speed: $M = 0.54$ to $M = 0.71$
Flying height 11 km
Range: 4765 km to 5430 km
Mach operating speed: $M = 0.72$ to $M = 0.95$
5. Take-off and landing runways for medium range transport, reference values
Take-off or landing weight: 200 t to 800 t
Airfield elevation 0 km
Take-off runway: 2180 m to 3470 m
Landing runway: 935 m to 1485 m
6. Approach speed on landing, reference value
Landing weight: 200 t
 $V_{\min} = 240 \text{ kph}$
7. Engines
Turbojet engines
Two-spool turbofan engines
Turboprop engines
Propeller piston engines

Application of the design methodology

Discussion of the limits of the method

The section “Limits for the application” lists limit and reference values for basic initial data and associated flight performance results which the user of the design method should observe.

In addition, six aeroplane configurations are named to which the method is tailored.

The flight performance values (range and mach operating speed) are only given for a flying weight of 200 t and one aeroplane configuration (aeroplane with rear elevator unit), but are also valid for the complete range of flying weights from 200 t to 800 t, as all weight classes have the same flight performance values when certain conditions are fulfilled – see study phase 1.

The flight performance values (range and mach operating speed) for other possible aeroplane configurations can be determined relatively easily with the aid of the results table in study phase 8 by multiplying the given flight performance values (for an aeroplane with a rear elevator unit) by the relevant factor.

In addition to the flight performance values, calculation results are given for take-off and landing runways, which are valid for the complete flying weight range from 200 t to 800 t but which only belong to the configuration of an aeroplane with a rear elevator unit.

Further calculation results for take-off and landing runways of other possible configurations are given for the take-off and landing weight of 200 t for (2), (3) and (5) and 250 t for (4) in document 35.

The information given in the section “Limits for the application” are a result of the study phases 1 to 13.

Application of the design methodology

Application of the design methodology

The following explanations refer to the abridged versions 1 to 11 of the PhD thesis.

For the application of the design methodology it is useful to write a separate section, which again contains an undivided flow chart of the methodology and which also lists the relevant work blocks 1 to 7 of the individual planning sections or phases (see study phase 5).

The overview is improved if the content of the various work blocks is described not in the flow chart itself but on separate sheets (see pages 2 to 4).

The content of work blocks 1 and 2 is described on page 2.

In block 1, the parameters which are calculated one after the other are named and the corresponding formula numbers from study phases 1, 2 and 3 also specified.

In block 2, all base data of study phases 1, 2 and 3, the names and values are given again in the order required for the formulae of block 1.

The content of work blocks 3, 4 and 5 is described on page 3.

In block 3, the names and values of all result data of study phases 1, 2 and 3 are given as they result in sequence based on the formulae block 1.

Block 4 contains the design results of the drawings which result from the result data of block 3 and from the configuration descriptions of study phases 3 and 4.

Block 5 shows how aerodynamic parameters and flight performance parameters can be determined for the various designs.

For calculation with a calculator, the relevant formula numbers from study phase 8 are specified.

For calculation with a PC, the relevant program names from file 2 or on the CD-R are given.

Block 5 also shows aerodynamic parameters and flight performance parameters.

The content of work blocks 6 and 7 is described on page 4.

Block 6 is used when one or more of the configurations are to be scaled. Different scaling methods are possible here.

For scaling, the relevant formula numbers from study phase 11 are specified.

Block 7 contains the main results for the scaled configurations.

These are aeroplane weights, flight performance parameters and flying characteristics.

Application of the design methodology

Block 1, with the formulae for calculation of the parameters for configuration 1:

flight time (7) summary 1
range (8)

height of cargo compartment and summary 2
width of cargo compartment (14)
length of cargo compartment (15) to (16)

wing and summary 3
horizontal stabiliser layout (18) to (26)

length of fuselage (27) summary 3
engine pod layout (28) to (30)

Block 2, with input data for the formulae of block 1:

$(W_E/W_{\max})_{\text{aeroplane}} (-)$ 0.5 summary 1
SFC (lb/(lbf · h)) 0.8
V (km/h) 600
 $C_D/C_L (-)$ 0.05
 $W_{\max} (t)$ 200

$W_{\max} (t)$ 200 summary 2
 $W_{\text{spec, aeroplane}} (t/m^3)$ 0.2
 $h_0, \text{aeroplane}^3 (m^3)$ 1000
 $h_0^3 (m^3)$ 250
 $k_{\text{aeroplane}} (-)$ 0.125
k (-) 0.5

$W_{\max} (t)$ 200 data 1 summary 3
 $V_{\min} (m/s)$ 66.67
 $C_{L\max} (-)$ 1.8
k (-) 0.0415
 $\lambda_s (-)$ 0.4
—
 $V_0 (-)$ 1.44
c (m) 7.25
 $l_{s,s} (m)$ 27
 $\lambda_s (m)$ 0.35
 $C_{D0} (-)$ 0.015
 $\phi_s (\text{degrees})$ 15
 $\phi_{s,s} (\text{degrees})$ 22

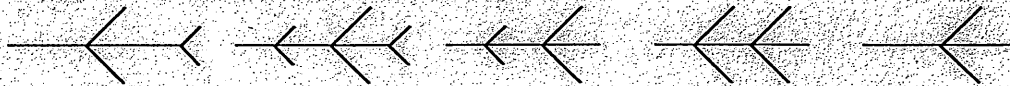
$l_{\text{aeroplane}} (m)$ 40 data 2 summary 3
 $h_{\text{aeroplane}} (m)$ 5
 $W_{\max} (t)$ 200
 $V_{\text{opt}} (m/s)$ 166.67
 $C_D/C_L (-)$ 0.05
 $l/d_I (-)$ 2.9

Application of the design methodology

Block 3, with results from the formulae of block 1:

T (h)	6.25	(7)	summary 1
R (km)	3750	(8)	
$h_{\text{aeroplane}}$ (m)	5	(14)	summary 2
$b_{\text{aeroplane}}$ (m)	5		
$l_{\text{aeroplane}}$ (m)	40	(15) to (16)	
S (m ²)	400	(18) to (26)	summary 3
$(W_{\text{max}}/S)_{\text{aeroplane}}$ (t/m ²)	0.5		
b_s (m)	55.4		
A_s (-)	7.7		
λ_s (-)	0.4		
S_s (m ²)	155		
b_s (m)	23		
λ_s (-)	0.35		
C_{Lopt} (-)	0.6		
φ_s (degrees)	15		
$\varphi_{s,s}$ (degrees)	22		
l_{fuselage} (m)	57.5	(27)	summary 3
l_{engine} (m)	8.12	(28) to (30)	
$d_{\text{I, engine}}$ (m)	2.8		
S_{I} (m ²)	6		

Block 4, to design the various configurations:



Block 5, for performance calculation of the designed configurations:

Calculation of C_{D0} and k with calculator: summary 8
Formulae (61) to (68)

Calculation of flying performance with calculator:
Formulae (76) to (80)

Calculation of C_{D0} with the PC-programs: file 2, CD-R
CW02TAB
CW02TAB2
CW02TAB4
CW02TAB5

Calculation of ranges with the PC-programs:
KONFPRINZ1
KONFPRINZ1A
KONFPRINZ1B, with velocities

Calculation of take-off and landing distance with the PC-program: ROLLSTRECKE

Application of the design methodology

Block 6, for scaling the designed configurations:

Determination of scaling factors:

summary 11

Formulae (125) and (129) or with

Scaling factor functions (131) and (132)

Scaling method 1 with scaling factors

Scaling method 2 with different length of the overall cargo compartment

Scaling method 3 with scaling factors

and different length of the overall cargo compartment

Block 7, for important results of the scaled configurations:

2 tables of results:

summary 5

Weight categories with flying performance and payload

Weight categories with flight qualities and payload accelerations

Application of the design methodology

Example for aeroplane design (1), study phase 3

Input data:

$$(W_E/W_{\max})_{\text{aeroplane}} = 0.5$$

summary 1

$$\text{SFC} = 0.8 \text{ lb}/(\text{lb} \cdot \text{h})$$

$$V = 600 \text{ km/h (at flying height 7 km)}$$

$$C_D/C_L = 0.05$$

$$W_{\max} = 200 \text{ t}$$

Results:

$$(7): \quad T = (1 - (W_E/W_{\max})_{\text{aeroplane}} - (W_{\text{Pay}}/W_{\max})_{\text{aeroplane}}) \cdot (1/\text{SFC})_{\text{aeroplane}} \cdot (1/(C_D/C_L))_{\text{aeroplane}}$$

$$T = (1 - 0.5 - 0.25) \cdot (1/0.8) \cdot (1/0.05) = 6.25 \text{ h}$$

$$(8): \quad R = (1 - (W_E/W_{\max})_{\text{aeroplane}} - (W_{\text{Pay}}/W_{\max})_{\text{aeroplane}}) \cdot (1/\text{SFC})_{\text{aeroplane}} \cdot (V/(C_D/C_L))_{\text{aeroplane}}$$

$$R = (1 - 0.5 - 0.25) \cdot (1/0.8) \cdot (600/0.05) = 3750 \text{ km}$$

Input data:

$$W_{\max} = 200 \text{ t}$$

summary 2

$$W_{\text{spec, aeroplane}} = 0.2 \text{ t/m}^3$$

$$h_{0, \text{aeroplane}}^3 = 1000 \text{ m}^3$$

$$h_0^3 = (1/4) \cdot h_{0, \text{aeroplane}}^3 = 250 \text{ m}^3$$

$$k_{\text{aeroplane}} = 1/8$$

$$k = 1/2$$

Results:

$$(14): \quad h = b = h_0 \cdot k^{1/3}$$

$$h = b = 1000^{1/3} \cdot (1/8)^{1/3} = 1000^{0.3333} \cdot 0.125^{0.3333} = 10 \cdot 0.5 = 5 \text{ m}$$

$$h = b = 250^{1/3} \cdot (1/2)^{1/3} = 250^{0.3333} \cdot 0.5^{0.3333} = 6.298 \cdot 0.794 = 5 \text{ m}$$

$$(15): \quad l = h/k$$

$$l = 5/(1/8) = 40 \text{ m} \quad \text{overall cargo compartment}$$

$$l = 5/(1/2) = 10 \text{ m} \quad \text{cargo compartment}$$

Application of the design methodology

Example for aeroplane design (1), study phase 3

Input data for results 1:

$$W_{\max} = 200 \text{ t}$$

$$V_{\min} = 66.67 \text{ m/s (at flying height 0 km)}$$

$$C_{L\max} = 1.8$$

$$k = 0.0415$$

$$\lambda_s = 0.4$$

$$\bar{c} =$$

$$V_0 = 1.44$$

$$c = 7.25$$

$$l_{s,s} = 27 \text{ m}$$

$$\lambda_s = 0.35$$

$$C_{D0} = 0.015$$

$$\varphi_s = 15^\circ$$

$$\varphi_{s,s} = 22^\circ$$

summary 3

Results 1:

$$(18): S = W_{\max} / (W_{\max} / S)_{\text{acropplane}}$$

$$(19): (W_{\max} / S)_{\text{acropplane}} = (\rho / 2) \cdot V_{\min}^2 \cdot C_{L\max}$$

$$(W_{\max} / S)_{\text{acropplane}} = (0.125 / 2) \cdot 66.67^2 \cdot 1.8 = 500 \text{ kp/m}^2 = 0.5 \text{ t/m}^2$$

$$S = 200 / 0.5 = 400 \text{ m}^2$$

$$(20): b_s = (A_s \cdot S)^{1/2}$$

$$(21): A_s = 1 / (\pi \cdot k)$$

$$A_s = 1 / (\pi \cdot 0.0415) = 7.67$$

$$b_s = (7.67 \cdot 400)^{1/2} = 55.39 \text{ m}$$

$$(22): \lambda_s = c_{is} / c_{rs}$$

$$c_{rs} = 2 \cdot c \cdot (1 / (1 + \lambda_s)) = 2 \cdot 7.25 \cdot 0.7143 = 10.36 \text{ m}$$

$$c_{is} = 2 \cdot c \cdot (\lambda_s / (1 + \lambda_s)) = 2 \cdot 7.25 \cdot 0.2857 = 4.14 \text{ m}$$

$$\lambda_s = 4.14 / 10.36 = 0.4$$

$$(23): S_s = \bar{V}_0 \cdot (S \cdot c) / l_{s,s}$$

$$(24): b_s = S_s / ((c_{is} + c_{rs}) / 2)$$

$$(25): \lambda_s = c_{is} / c_{rs}$$

$$c_{rs} = 2 \cdot b = 10 \text{ m}$$

$$c_{is} = c_{rs} \cdot \lambda_s = 3.5 \text{ m}$$

$$\lambda_s = 0.35$$

$$S_s = 1.44 \cdot (400 \cdot 7.25) / 27 = 154.67 \approx 155 \text{ m}^2$$

$$b_s = 155 / ((3.5 + 10) / 2) = 155 / 6.75 = 22.96 \approx 23 \text{ m}$$

$$(26): C_{Lopt} = (C_{D0} / k)^{1/2}$$

$$C_{Lopt} = (0.015 / 0.0415)^{1/2} = 0.6$$

Application of the design methodology

Example for aeroplane design (1), study phase 3

Input data for results 2:

$$l_{\text{aeroplane}} = 40 \text{ m}$$

$$h_{\text{aeroplane}} = 5 \text{ m}$$

$$W_{\text{max}} = 200 \text{ t}$$

$$V_{\text{opt}} = 166.67 \text{ m/s (at flying height 7 km)}$$

$$C_D/C_L = 0.05$$

$$l/d_l = 2.9$$

summary 3

Results 2:

$$(27): l_{\text{fuselage}} = l_{\text{aeroplane}} + 3.5 \cdot h_{\text{aeroplane}}$$

$$l_{\text{fuselage}} = 40 + 3.5 \cdot 5 = 57.5 \text{ m}$$

$$(28): l_{\text{engine}} = (l/d_l)_{\text{engine}} \cdot d_{l, \text{engine}}$$

$$(29): d_{l, \text{engine}} = (4 \cdot S_l / \pi)^{1/2}$$

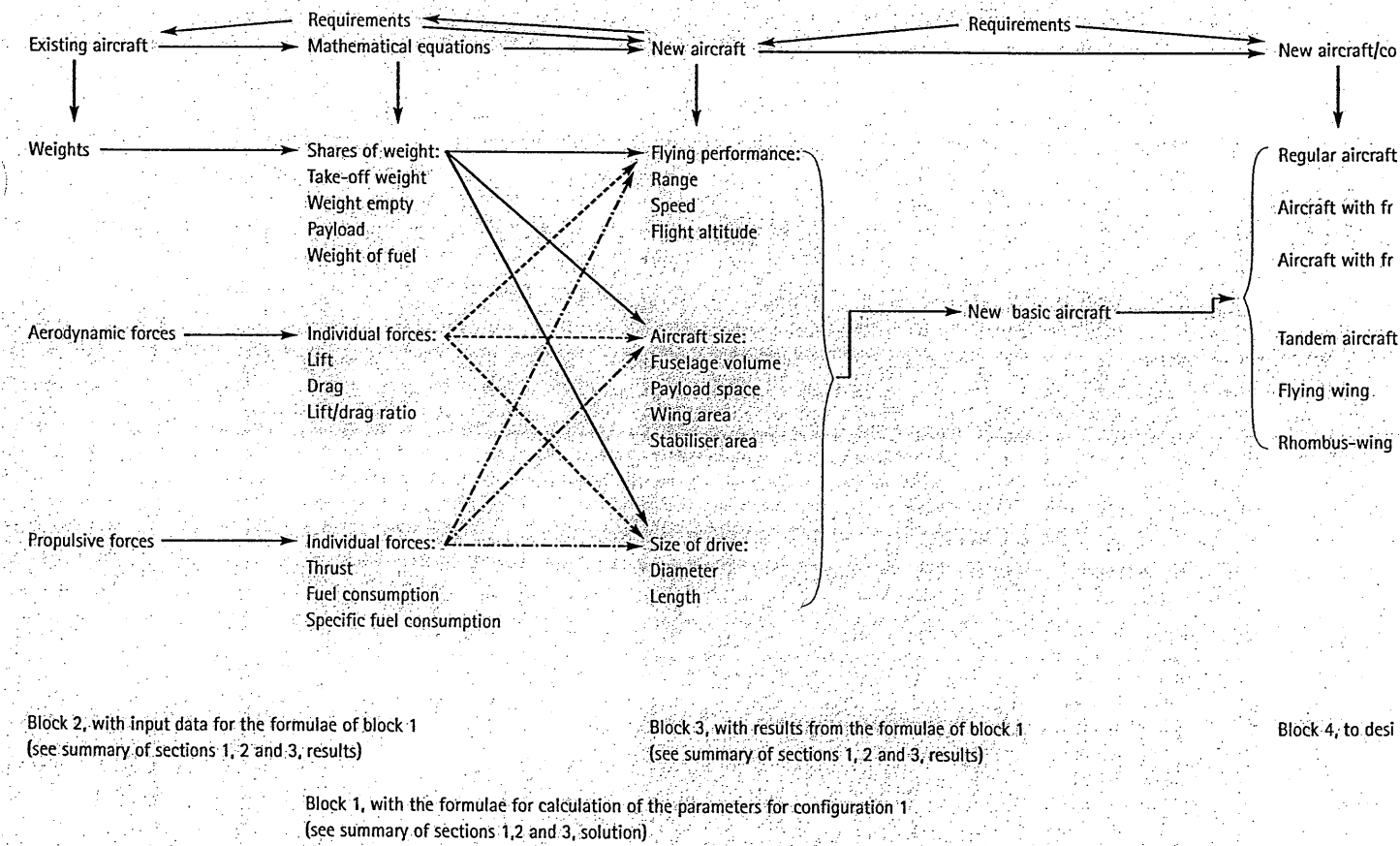
$$(30): S_l = (C_D/C_L) \cdot W_{\text{max}}^2 / (\rho \cdot V_{\text{opt}}^2)$$

$$S_l = 0.05 \cdot 200 \cdot 10^3 / (0.060121 \cdot 166.67^2) = 5.99 \text{ m}^2 \approx 6 \text{ m}^2$$

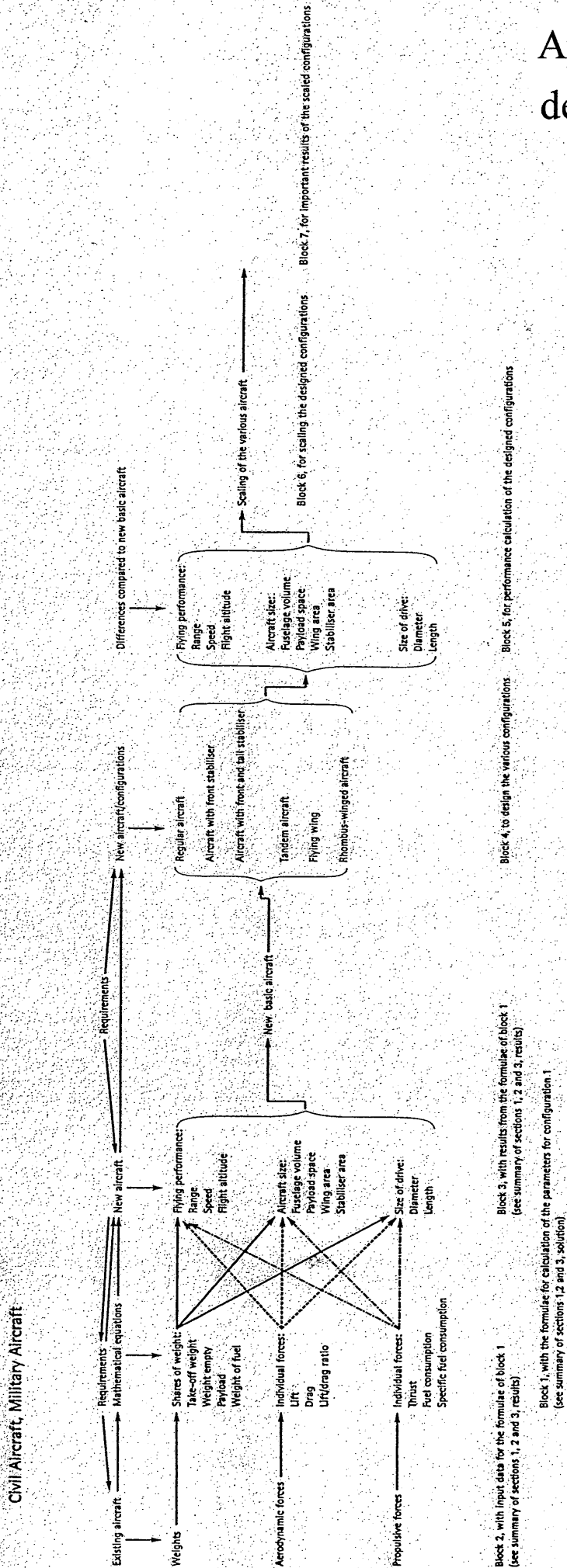
$$d_{l, \text{engine}} = (4 \cdot 6 / \pi)^{1/2} = 2.76 \approx 2.8 \text{ m}$$

$$l_{\text{engine}} = 2.9 \cdot 2.8 = 8.12 \text{ m}$$

Civil Aircraft, Military Aircraft



Application of the design methodology



CHAPTER 8

Overall discussion and outlook

Overall discussion and outlook

General discussion of results

The result of this paper is a well structured design method for transport aeroplanes with a take-off weight of 200 t to 1000 t.

The method allows very different aeroplane configurations to be designed and the main flying performances thereof to be calculated.

The main configurations, also referred to as basic configurations, are:

- aeroplane with rear stabiliser (1)
- aeroplane with front stabiliser (2)
- aeroplane with front and rear stabiliser (3)
- aeroplane with tandem arrangement of the wings (4)
- aeroplane without the normal stabiliser, wings alone (5)

To calculate performances, formulae were developed and user-friendly computer programs were produced.

The design method is divided into the following seven sections:

- 1: Mathematical equations
- 2: Existing aeroplanes, input data
- 3: New aeroplane, result data
- 4: New aeroplane, configurations
- 5: Differences compared with new basic aeroplane
- 6: Scaling of the different aeroplanes
- 7: Weight classes, requirements for performances/properties

The method also includes scaling of the configurations (see point 6) according to a 3-step process.

For this, study phase 11 contains scaling factors for the required maximum take-off weights of the basic configurations (1), (2), (4) and (5).

For configurations (1), (2), (4) and (5), the ranges

R_{Tmax} , R_{max} and $R_{max, Ferry}$ as well as the associated flying speeds V_{Tmax} and V_{Rmax} for the flying height $h = 7$ km were calculated with the programs.

In addition, the payload/range diagrams of R_{max} and R_{Tmax} were defined for the flying height $h = 7$ km for the basic configuration (1).

The range calculations cover the following transport categories:

- a) medium-range transport
- b) short-range transport
- c) long-range transport

With the aid of the computer programs, the flying performances for the four scaled basic configurations can be calculated, taking the relevant input data into account.

These results then belong to point 7 of the design method.

Overall discussion and outlook

Comment on the validation:

In the chapter “Validation of methodology”, a detailed description is given of how the validation of the design method was checked and what results were obtained (see also Appendix A, Document 45).

The section describes:

- studies on the validation of transport aeroplane configurations which were created with the method
- studies on the validation of range formulae for transport aeroplanes which were used in the method

Comments on problem and solution:

When given in a block and not in the text (several formula are given one below the other without a text), the formulae given in this section are written in the simplest sequence for understanding the calculation of individual results.

For example, first the formula of the main parameter required, then there follows the expression of the required sub-parameter in the formula for the main parameter.

Apart from a few additions, the formulae of the summaries are the same as those in the unabbreviated study reports, but all symbols are written in the English style.

Comments on the results:

The results given in this section are described per summary to the required degree.

The configurations, diagrams and results tables of the summaries are the same as in the unabbreviated study reports, but here too all symbols are written in the English style.

A more detailed discussion of the results is given in the unabbreviated study reports of file 1. (see also Appendix A, Study Work Phase 10, 10a and 14)

The chapter “Discussion of results” describes in detail the main individual study phases.

Overall discussion and outlook

Results table

PhD OBJECTIVES	Number of study phase Number of document	Comments
1.	Cover page	x title of PhD Thesis
2.	10, 10a 45, Validation calculations	x
3.	2, 3	x
4.	4	x
5.	10, 10a	(x)
6.	12	x
7.	11	x
CONSTRAINTS		
1.	11	x
2.	12	x
3.	3, 4	x
4.	10, 10a	x FAR 121.645 used
5.	7, 12	(x)
6.	8 35, Calculations no. 6	x
•	3	x
•	3	x
•	3	x
•	8 35, Calculations no. 6	x

x = covered

(x) = partly covered

Overall discussion and outlook

Comments on achievement of the PhD objectives

Objective 1:

This states everything that is to be developed.

This is achieved with a clear overview of titles for the thesis.

Objective 2:

This demands that the methodology developed is confirmed by comparisons with existing large transport aeroplanes. This is achieved in study phases 10 and 10a by recalculating the ranges from transport aeroplanes already in use with the new range formula and in document 45 by the redesign of 3 existing and 2 projected transport aeroplanes with the developed design and scaling formulae.

Objective 3:

This demands that the methodology is computer-aided or works with computer programs, so that a large number of configurations can be studied. This condition is given with the aid of the design formulae of study phase 3 and use of a calculator as well as 8 PC programs.

Objective 4:

The methodology should also allow the development of unconventional configurations. This can be done in study phase 4 with the aid of the design formulae and results of study phase 3.

Objective 5:

This demands that a number of cases be studied in order to produce a matrix of transport aeroplane requirements with regard to payload, range and flying speed. The influence of civil and military operations is to be determined in this context. This was achieved by the recalculation of ranges of 10 transport aeroplanes already in use in study phases 10 and 10a, for which data of the aeroplane manufacturers was necessary. This data is shown in tabular form.

Objective 6:

Here the results of 5 are to be checked in order to establish trends, by comparing configurations in special roles, so that the best solution for the fulfilment of the specified requirements can be found.

Corresponding studies were carried out in study phase 12.

Objective 7:

Here uncertainties are to be determined and discussed and recommendations for further studies are to be made.

Study phase 11 produced corresponding points, for example higher flying speed with scaling to very high maximum aeroplane weights.

Overall discussion and outlook

Restrictions

Restriction 1:

The payload range should be from 50 t to 400 t.

The scaling studies of study phase 11 produce a useful range of 50 t to 200 t for medium range transport.

Restriction 2:

The flight Mach number for cruise should be between 0.65 and 0.85.

With basic configuration 1 it is between 0.54 and 0.71 at a flying height of 7 km and between 0.72 and 0.875 at a flying height of 11 km – see study phase 12.

Restriction 3:

In particular, 4 basic configurations should be examined but quantitatively also a larger range.

This is dealt with in study phases 3 and 4.

Restriction 4:

Regulations JAR25 for civil transport aeroplanes and regulations DEF-STAN 00-970 for military transport aeroplanes should be taken into consideration. The manufacturers' data in study phases 10 and 10a only refer to regulations FAR 121.645.

Restriction 5:

Existing and future environmental regulations should be studied. A statement on this is made in study phase 7 and study phase 12 deals with wave drag or the sound barrier.

Restriction 6:

The best solutions in the context of the objectives should include the 4 conditions mentioned.

Relevant information is given in study phase 8, drawing files 1 to 4 and in document 35.

Overall discussion and outlook

Outlook

The new design method has shown how

- a) an already realistic initial transport aeroplane configuration can be produced
- b) with the aid of the initial configuration, 4 further transport aeroplane configurations can be developed so that 5 basic configurations are produced
- c) with the aid of the basic configurations, 6 additional, extended transport aeroplane configurations can be produced.

As with the basic configurations the individual fuselages, wing and stabiliser areas apart from configuration 4 are of the same size but are only arranged differently to one another, differences in flying performance result, which enable the configurations to be compared.

As the basic configurations were also scaled, a transport aeroplane configuration can be selected on the basis of take-off weight, payload and flight performance specifications as well as other aspects.

Based on this configuration, a more exact design could then be produced which corresponds to a conventional preliminary design

CHAPTER 9

Conclusion and recommendations

Conclusion and recommendations

Conclusions and recommendations

What results does this study produce?

The summaries of study reports 1 to 13 including appendix show a large number of individual results, which in particular serve the purpose of developing a useful design method that can be used without a large amount of drawings and mathematical aids.

The individual results are made up of:

- configuration drawings of different types
- result diagrams of flying performance and aerodynamics
- result tables of flying performance and aerodynamics
- result diagrams of engine type and engine size
- tables of aeroplane type and flying performance
- tables of aeroplane type, engine type and engine size
- result formulae of different types
- computer programs (small) for aeroplane resistances
- computer programs (small) for flying performances

In addition to already qualitatively known individual results, there is a large number of completely new results or findings, which are described in words in the overview report of files 1 and 2.

Where can the new design method be used?

If the method is new to the user, the summaries of study reports 1 to 13 should be available where possible.

The method can be used wherever the necessary know-how is available, i.e. in particular in an aeroplane design office.

How can the new design method be used?

If the summaries of study reports 1 to 13 are available, the following possibilities exist:

- a) working without calculations and using the configurations given in the summaries directly, or
- b) working with calculations and slightly modifying the configurations given in the summaries, or
- c) working with calculations and creating completely new configurations.

The design method described is suitable as a basis for systematic configuration studies for large transport aeroplanes, as its validity was confirmed by comparative calculations.

Conclusion and recommendations

Comments on continuation of study phases

What study phases are still to be completed so that the overall task is fulfilled?

The PhD objectives are essentially covered by study phases 1 to 12.

However, the original research plan has 18 study phases, so that 4 studies are still to be carried out if the overall task is to be completed.

So far 14 of the planned 18 study phases have been carried out.

What studies have priority based on the results so far?

Study phases 8 and 13 have shown that basic configuration 5 has clear range advantages compared to the other basic configurations 1, 2 and 4.

On the other hand, basic configuration 5 differs from the other basic configurations due to the (partial) replacement of vertical and horizontal stabiliser by thrust-vectoring nozzles on the engines.

As a thrust-vectoring nozzle control of the type planned here is currently only being tested in experimental aeroplanes (e.g. X31), the development of a transport aeroplane of configuration 5 would involve a certain development risk.

Problems could arise in the development of the necessary particularly safe, electrical control system with the associated regulators for nozzle, rudder and wing flaps.

The development costs for the control system would then be particularly high compared with familiar and to a large extent tested systems.

More clarity on this can only be provided by a more detailed configuration study, which point 18 of the original research plan also foresees for the best configuration in terms of performance.

The main focuses of this study will be on a) a draft for the vectoring nozzles and b) a concept for overall flight control (including nozzle control).

In addition, c) the wing flaps and the all-moving vertical stabiliser should be studied in detail.

Another main focus of the study would probably be on d) a weight estimate for the vectoring nozzles and for the complete flight control (including nozzle control).

What other studies are important based on the results so far?

In study phase 4, 6 unusual transport aeroplane configurations were developed, for which no flight performance data are available so far in this study.

It would be useful to produce a comparative table, similar to that in study phase 8.

CHAPTER 10

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(10)	F. Dubs Aerodynamik der reinen Unterschallströmung Verlag Birkhäuser AG, Basel/Stuttgart, 1954, Switzerland
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(14)	FAR 121.645 Treibstoffversorgung: Flugzeuge mit Turbinentriebwerken, nicht jedoch mit Propellerturbine; Linien- u. Charterflüge
(15)	John P. Fielding Introduction to Aircraft Design First published 1999 University Press, Cambridge, United Kingdom
(16)	Egbert Torenbeek Synthesis of subsonic airplane design An introduction to the preliminary design of subsonic general aviation and transport aircraft, with emphasis on layout, aerodynamic design, propulsion and performance 1976 Delft University Press, Netherlands
(17)	A. Mederer Theorie des erforderlichen Höhenleitwerkvolumens Computer-Abschrift vom 26.10.1998 Büro für Technische Studien, Birkhofstr. 11, 88636 Illmensee, Germany
(18)	W. Richter Flugmechanik B. G. Teubner Verlagsgesellschaft Leipzig, 1959, Germany

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(1)	Jane's All the World's Aircraft 2001- 2002 Jane's Information Group Coulson, Surrey, United Kingdom
(2)	Prof. Dr. Ing. Justin Kleinwächter Vorlesungen über Flugzeugbau, Teil 1 bis 4 Teil 1: Fluglehre (2 Teile) Teil 2: Entwurf von Flugzeugen Teil 3: Festigkeitslehre (2 Teile) Teil 4: Methoden der Tragflügelberechnung (2 Teile) Flugtechnisches Institut der Technischen Hochschule Danzig Danzig, Deutschland
(3)	Prof. Karl Nickel & Dr. Michael Wohlfahrt Tailless Aircraft in theory & practice Translation of the book "Schwanzlose Flugzeuge" printed in 1990 by Birkhäuser Verlag, Basel, Schweiz Edward Arnold, a division of Hodder Headline PLC, 338 Euston Road, London NW1 3BH by The Bath Press, Avon Great Britain
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File 1 and 2 of the study documents were currently considered as an appendix to this thesis version.

File 2 can be abbreviated.

APPENDIX A

CRANFIELD UNIVERSITY

A. MEDERER

**THE DEVELOPMENT OF A DESIGN METHODOLOGY
FOR LARGE CARGO AIRCRAFT**

SCHOOL OF ENGINEERING

PhD THESIS

APPENDIX A

CRANFIELD UNIVERSITY

SCHOOL OF ENGINEERING

PhD THESIS

Academic Year 2007/2008

A. MEDERER

**The Development of a Design Methodology
For Large Cargo Aircraft**

Supervisor:

J. P. Fielding

November 2008

**This thesis is submitted in partial fulfilment of the requirements
for the degree of PhD**

Contents of File 1:

Study Work Phases	Number of dividers
Study Work Phase 1 Pre-Examinations on Important Characteristic Quantities of Transport or Cargo Aircraft, for the Purpose of allowing for Initial Principal Data Statements for an Aircraft Design to be made.	1
Study Work Phase 2 Preliminary Research on the Size and Dimensioning of the Cargo Compartment of Transport or Freight Aircraft	2
Study Work Phase 3 Determination of Possible Wing/Fuselage Arrangements for Large Transport or Cargo Aircraft	3
Study Work Phase 4 Determination of Possible Wing/Fuselage Arrangements for Large Transport or Cargo Aircraft	4
Study Work Phase 5 Methodology for a Systematic Design Study on a Number of Configurations for Large Aircraft, in Particular for Cargo Aircraft	5
Study Work Phase 6 Variable Aircraft Polar for Design Examinations on Large Transport or Cargo Aircraft.	6
Study Work Phase 7 Engines and Propulsions for Large Transport or Cargo Aircraft	7
Study Work Phase 9 Objectives and Assumptions for Projecting Large Transport or Cargo Aircraft	8
Study Module 8 Determination or calculation of configuration and performance data of the four basic aircraft concepts	9
Study Work Phase 10 Re-Calculation of the Ranges of Ten Built Transport Aircraft and Calculation of the Ranges for Configuration Scheme 1	10
Study Work Phase 10a Re-Calculation of the Ferry Ranges of Ten Built Transport Aircraft and Calculation of the Ferry Ranges for Configuration Scheme 1	11
Study Work Phase 11 Scaling the Basic Configurations	12
Study Work Phase 12 Flight and Transport Task of Large Transport or Cargo Aeroplanes	13
Study Work Phase 14 Flight Characteristics of the Four Basic Configurations	14
Study Work Phase 13 Which of the scaled basic designs best fulfils the mission values 12 ?	15

Study Work Phase 1

Pre-examinations on important characteristic quantities of transport or cargo aircraft, for the purpose of allowing for initial principal data statements for an aircraft design to be made.
Take-off weight, weight empty, payload, and range ratios.

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: February 10th, 1999

Signature: A. Mederer

Number of pages: 18

Abstract

This work report outlines the results of a study aimed at ascertaining the quantities that must first be known for planning and designing large cargo aircraft and determining their context. It has turned out that simple relations can be mathematically derived for the corresponding spectrum of aircraft.

With the help of these equations, it is possible to construct the data framework for the design aircraft, provided that a minimum quantity of information is given (e. g. max take-off weight and range).

In order to depict the relations more illustratively, they were entered into a design diagram. This allows for directly reading linked data for any minimum parameter.

Two fundamental regularities resulted from itemising the mathematical connections. They are described in principles 1 and 2 on page 5.

The design diagram also reveals that it is expedient to lay down three layout categories for a certain aircraft concept which differ in payload and range. More information on this can be found on pages 14 and 15.

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures, and Systems

Study Work Phase 2

Preliminary research on the size and dimensioning of the cargo compartment of transport or freight aircraft.

Correlation between payload, freight volume and cargo compartment aspect ratio.

Definition of an overall volume for freight aircraft and freight.

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: March 24th, 1999

Signature: A. Mederer

Number of pages: 15

Abstract

In this Work Report, I shall detail the results of a study which starts immediately from Report 1 and is based on the partial results gained there.

First, the Report reveals how a number of algebraical equations were derived which describe a plain cargo-compartment geometry (height, width, length, and aspect ratio) in the case of a given volume. Subsequently, these mathematical functions are depicted by means of four diagrams which shall allow for reading the cargo-compartment parameters and facilitate dimensioning tasks.

In order to graphically outline the design principle of the cargo compartment, a geometrical graph (cubical graph) was thought up and introduced in the report. The representation takes the distribution of weight in four sections for payload and fuel, as exposed in the first study, into account. They correspond with the three different transport operations.

The cubic graph reveals another way of defining an overall aircraft volume and of calculating the aspect ratio of an aircraft or the length of the fuselage.

Thereafter, the exactness of this proceeding is proved by means of example calculations for the cargo compartment, the fuel tank, and the overall aircraft volume.

In conclusion of this study report, a schematic diagram for a transport or cargo aircraft is shown which includes the described distribution of weight and does not only reveal the cargo-compartment and fuselage length, but also states the corresponding wing span and area. Work Report 3 shall describe how these two quantities are determined.

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the Study Programme

PhD Design, Structures and Systems.

Study Work Phase 3

Determination of Possible Wing/Fuselage Arrangements for Large Transport or Cargo Aircraft

Schematic diagrams with descriptions of:

- aircraft with tail stabiliser (normal)
- aircraft with front stabiliser
- aircraft with front and tail stabiliser
- aircraft with tandem arrangement of the wings
- aircraft without stabiliser (flying wing)

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: May 8th, 1999

Signature: A. Mederer

Number of pages: 32

– study identification sheet –

Abstract

In this Study Work Phase, schematic diagrams of wing/fuselage arrangements will be depicted for five different transport or cargo aircraft types.

The following known and tested configurations are concerned:

schematic diagram 1	aircraft with tail stabiliser (normal)
schematic diagram 2	aircraft with front stabiliser
schematic diagram 3	aircraft with front and tail stabiliser
schematic diagram 4	aircraft with two tandem-arranged wings
schematic diagram 5	aircraft without stabiliser (flying wing)

The schematic diagrams and configurations have been drafted for a max take-off weight of 200 t to 300 t which has been taken as a basis for several example calculations in studies 1 and 2 and can be found in the medium range of large transport aircraft. Thus, the diagrams start from rather realistic presumptions.

All schematic diagrams are described in detail.

For diagram 1, which serves as an initial or basic configuration for all other diagrams, calculations for the wing load and the wing area, the wing span, as well as the wing aspect ratio and the flight speed are also included.

Provided that the take-off weight and the wing area remain the same, the data established in this process approximately also apply to the other configurations.

The geometrical and three-dimensional aspects that are essential for the respective configurations are included in the description.

Specifications respecting the position of the centre of gravity of the aircraft and important configuration-dependent quantities referring to the longitudinal stability are discussed briefly.

In order to organise the aircraft configurations and their descriptions systematically, all depictions have been based on the same schematic diagram description set-up (see page 3).

The items listed therein are taken into account for all depicted aircraft types (for more details, see page 17).

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures and Systems.

Study Work Phase 4

Determination of Possible Wing/Fuselage Arrangements for Large Transport or Cargo Aircraft

Schematic diagrams with descriptions of:

- Aircraft with Three Tandem-Arranged Wings of the Same Size
- Aircraft with Wings Arranged in the Shape of a Rhombus
- Aircraft with Tail Stabiliser and Double Fuselage
- Aircraft with Front Stabiliser and Double Fuselage
- Aircraft with Two Tandem-Arranged Wings of the Same Size and Double Fuselage
- Aircraft with Front Stabiliser and Double Fuselage, Outer Fuselages having a Larger Diameter

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: July 11th, 1999

Signature: A. Mederer

Number of pages: 30

Abstract

In this Study Work Phase, schematic diagrams of wing/fuselage arrangements will be depicted for six different transport or cargo aircraft types.

The following hardly known or unknown configurations are concerned:

- | | |
|----------------------|--|
| Schematic Diagram 6 | Aircraft with Three Tandem-Arranged Wings of the Same Size |
| Schematic Diagram 7 | Aircraft with Wings Arranged in the Shape of a Rhombus |
| Schematic Diagram 8 | Aircraft with Tail Stabiliser and Double Fuselage |
| Schematic Diagram 9 | Aircraft with Front Stabiliser and Double Fuselage |
| Schematic Diagram 10 | Aircraft with Two Tandem-Arranged Wings of the Same Size and Double Fuselage |
| Schematic Diagram 11 | Aircraft with Front Stabiliser and Double Fuselage, Outer Fuselages having a Larger Diameter |

The schematic diagrams and configurations have been drafted for a max take-off weight of 200 t to 300 t which has been taken as a basis for several example calculations in studies 1 and 2 and can be found in the medium range of large transport aircraft. Thus, the diagrams start from rather realistic presumptions.

All schematic diagrams are described in detail.

For diagram 1, which has been described in Study Work Report 3 and which serves as an initial or basic configuration for all other diagrams, calculations for the wing load and the wing area, the wing span, as well as the wing aspect ratio and the flight speed were also included.

Provided that the take-off weight and the wing area remain the same, the data established in this process approximately also apply to the other configurations.

Four of the aircraft-configuration schemes shown here are not known yet or deviate significantly from what is known; therefore, it seems appropriate to conduct a number of pre-examinations in order to allow for an initial comparison with basic scheme 1.

These pre-examinations shall be described in Study Work Report 5.

The geometrical and three-dimensional aspects that are essential for the respective configurations are included in the description on hand.

Specifications respecting the position of the centre of gravity of the aircraft and important configuration-dependent quantities referring to the longitudinal stability are discussed briefly.

In order to organise the aircraft configurations and their descriptions systematically, all depictions have been based on the same schematic diagram description set-up (see page 3).

The items listed therein are taken into account for all depicted aircraft types (for more details, see pages 4 and 5).

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures and Systems.

Study Work Phase 5

Methodology for a

Systematic Design Study on a Number of Configurations for Large Aircraft, in Particular for
Cargo Aircraft

Depiction No. 1

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: October 11th, 1999

Signature: A. Mederer

Number of pages: 8

Abstract

In this Study Work Phase, the methodology on which the Research Programme is based will be described or depicted.

So far, the description only includes those elements, the examination or portrayal of which has been recognised as particularly important. The individual steps have only become clear over the course of Study Works 1 through 4 and are therefore not described in the first draft of the Research Programme or in the flow chart belonging to it.

A number of the elements depicted in the methodology are also included in Research Programme 1, however.

The work to be done according to the first draft of the Research Programme influence the methodology as we go along, requiring the latter to progressively be supplemented and improved. The procedure depicted here has been elaborated in handwriting during a visit to Cranfield University and is brought into a more legible form by this document.

All details have remained unchanged compared to the hand-written version, except for the numerical values of the cargo compartment.

These values have undergone minor corrections and have been precisely adjusted to the medium range transport defined in Study Work Phase 1.

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures and Systems.

Study Work Phase 6

Variable Aircraft Polar for
Design Examinations on Large Transport or Cargo Aircraft

Relations between Lift, Drag,
Lift/Drag Ratio, and Wing Flap Deflection

Cranfield University, College of Aeronautics
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Created on: December 15th, 1999

Signature: A. Mederer

Number of pages: 35

– study identification sheet –

Abstract

In Study Work Report 6, a variable aircraft polar is described respectively with and without wing flap deflection in a mathematical and an algebraical form.

The variability is achieved by means of alterable, constant quantities in the equations which have been given different numerical values for various aircraft designs. With the help of these alterable quantities, the polar can be adjusted to an already existing aircraft or it can approximately describe the aerodynamic qualities of such an aircraft.

The form of the variable polars is that of a quadric parabola which is precise enough for the linear range of attack.

For a transport aircraft in the medium weight category (200 t), the polar is adjusted correspondingly. This adjustment also takes positive and negative deflections of the wing flaps into account, so it is possible to examine or calculate the most important flight statuses.

On page 24, this polar of the medium aircraft category is depicted graphically both without and with negative wing flap deflection. The negative wing flap deflection shall compensate for the reduction of the flying weight which takes place as the aircraft covers long distances. More detailed information on this can be found on page 23.

On page 26, the same aircraft polar is depicted without wing flap deflection. Two particularly important flight points are indicated: the point for best gliding and for least descent. More information on this can be found on pages 13 and 14.

Page 28 also shows this aircraft polar without wing flap deflection. Here, other than on page 26, three significant flight points are indicated for comparison: the point for best gliding, the point for least descent, and that for the maximum range.

On pages 16 to 20, the aerophysical interrelationship between these three flight points is explained in detail.

Subsequently, the numerical values of the characteristic quantities (C_W/C_A), (C_W^2/C_A^3), and (C_W^2/C_A) are determined for the depicted aircraft polar without wing flap deflection. These numerical values can then be used for preliminarily calculating the range, the flight speed, the required thrust, and the rate of climb and of descent.

Apart from the numerical values mentioned, the values of the aerodynamic quantities such as the C_{Amax} with and without wing flap deflection are also important for calculating the take-off and the landing speed of a large transport aircraft. A number of calculations shall be carried out for this as well. The diagram $C_A = f(\alpha, \eta)$ on page 34 shows which C_{Amax} -values are possible with plain wing flaps without a slot.

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures and Systems.

Study Work Phase 7

Engines and Propulsions for
Large Transport or Cargo Aircraft

Comparison of
Turbojet, Turbofan, Turboprop
and Propeller Piston Engines

Cranfield University, College of Aeronautics
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Created on: April 4th, 2000

Signature: A. Mederer

Number of pages: 43

– study identification sheet –

Abstract

For the preliminary draft and/or design of a large transport or freight aeroplane, more information is required regarding the engines to be used for the aeroplane in addition to the basic data described in Study Work Phases 1, 2, 3, 4 and 6.

In the present Study Work Phase 7, the pertinent engines of existing large transport aeroplanes will be compared based on corresponding comparison parameters. Comparison parameters are to this purpose engine data which have a direct impact on the design.

The comparison will be made in graphs so that the special engine data form points on a curve and/or are values of an empirical or mathematical function. Trends will thus become visible, and intermediary solutions can be gathered.

This study shall present the following graphs:

- Engine main-pass ratio = f (engine external dimension ratio)
- Engine main-pass ratio = f (engine by-pass ratio)
- Engine main-pass ratio = f (engine velocity ratio, engine by-pass ratio)

This report contains an engine external dimension comparison in addition to the comparison graphs. Based on the maximum dimensions for a basic turbojet engine, this comparison shall show how the external dimensions change when different external and internal operating conditions (operating parameters) are given. Example calculations will be conducted referring to the graphs and comparisons to elucidate the relationships more clearly.

Schematic diagrams of the pertinent propulsions are depicted on pages 10 and 11 to provide a better understanding of the various engine types.

All of the examples refer to the basic configuration according to schematic diagram 1 (200 t aircraft) as described in Study Work Phase 3.

The engine external dimension comparison also proceeds from a basic engine based on schematic diagram 1.

To create the graphs and conduct the calculations, it was necessary to re-estimate the essential physical rudiments for the generation of thrust by means of turbojet and/or bypass turbojet engines beforehand; see pages 13 – 15.

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures and Systems.

Study Work Phase 9

Objectives and Assumptions for Projecting Large Transport or Cargo Aircraft

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Created on:..... 18. 12. 2000

Signature: • A. Mederer

Number of pages: 7

- study identification sheet -

Overview

In this section of the study paper main and secondary objectives are listed that have become recognizable due to the work accomplished so far in accordance with the research plan.

These real objectives must be achieved if the intermediate as well as the end results depicted in the research plan are to be realised.

The objectives specified here also depend on the methods used while working on the various points in the research plan.

By objectives is meant here concretely designated and/or formulated technical, project-related results.

The real objectives are listed in a sequence such that the main result and underneath this the intermediate results are given. When elaborating the partial goals item 5 shall be aimed at first and item 1 last.

A prerequisite for objective 7 is that the real objectives 2 to 6 be elaborated first.

On request I presented the list of these objectives to Professor Fielding on the occasion of my second visit to Cranfield on 14 November. He then formulated objectives for his part and wrote them down in a second list which is attached to my representations herein as an important working document that points the way.

The past method of documenting all the study papers relating to the PhD course of studies in the form of reports on the section of the study paper has proven itself so far and thus these working documents should also be recorded in a short report.

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures and Systems.

Study Module 8

Determination or calculation of configuration and performance data
for the four basic aircraft concepts

Data of:

Aircraft with rear control unit

Aircraft with front control unit

Aircraft with tandem arrangement of the wings

Aircraft without control unit (all-wing)

Cranfield University, College of Aeronautics

Course of Studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Date: 15.05.2001

Signed: A. Mederer

Number of pages: 38

Summary

In study module 8, fundamental configuration and performance data relating to four selected basic configuration models are determined or calculated.

Some of the configuration data for the basic configuration models were already featured in module 3 in the plan views of the aircraft; the rest were determined as part of this module based on the side views.

The available performance data for the four selected basic configuration models are based partly on aeronautical relationships from module 6 and partly on new equations derived from those of module 6.

The equations in module 8 feature constants which vary from one configuration model to another and have to be precisely calculated.

These constants are the C_{w0} and K-factors for the symmetrical aircraft polars.

The C_{w0} factor determines the zero drag and the K-factor the induced drag of the aircraft.

The results of the C_{w0} and K-factor calculations are represented both individually (see 2.) and collectively in ready-reckoners (see 3. and 4.).

These calculated results are also compared in a polar comparison diagram which allows an initial assessment of the aerodynamic quality of the four basic aircraft.

The flight performance results are grouped in a results table as the data involved relate to defined polar points (page 32).

Module 8 also includes four drawing portfolios and a roll of posters. The configuration data and corresponding point-based flight performance data are included in each drawing portfolio so that all the results obtained so far are available for each basic aircraft.

The calculations in module 8 are only based on initial data which are formally defined (by mathematical formulae) or well documented by measuring results (see 8.).

This report does not claim to be complete or definitive.

It is submitted as evidence of research work as part of the course of study

PhD Design, Structures and Systems.

Study Work Phase 10

Re-calculation of the ranges of ten built transport aircraft and
calculation of the ranges for Configuration Scheme 1

Application of the New Range Formulas for Transport Aircraft

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: October 25th, 2001

Signature: A. Mederer

Number of pages: 54

– study identification sheet –

Abstract

In this report, the ranges of ten transport aircraft which have been built or are currently being operated shall be re-calculated, and these re-calculations shall be explained.

The explanations have been set up in a way that all calculations can be comprehended and the influence of individual initial data becomes apparent.

The calculations are based on formulas and fundamental data which are detailed in section 1.

The calculations respecting the individual aircraft have all been carried out following the same basic procedure, since the aim was to always use the same set of formulas. Depending on how complete the initial sets of data for the various aircraft were, the set of formulas was either extended or reduced.

The set of formulas used gives the following information:

Basic set of formulas:

- maximum range with maximum payload, without reserves
- maximum range with maximum payload, with reserves
- maximum range without payload, without reserves

Extended set of formulas

- range, based on maximum flight time with maximum payload, without reserves
- range, based on maximum flight time with maximum payload, with reserves
- range, based on maximum flight time without payload, without reserves

In order to allow for the calculated ranges of the ten built transport aircraft to be compared with the calculated ranges of the previous configuration schemes, in the framework of this study, the range values of Configuration Scheme 1 have been re-calculated with the described set of formulas.

These calculations were carried out both for Configuration Scheme 1, using the basic engines, and for Configuration Scheme 1, using the alternative engines.

The ranges of the built transport aircraft and of Configuration Scheme 1 resulting from the set of formulas, have been juxtaposed in a table for comparison purposes. In order to allow for the calculation results referring to the built aircraft to be evaluated, the difference between the calculated range and the actual range has been stated in percentage numbers in the table.

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures and Systems.

Examination of the Results of the Calculations:

In order to make it easier to evaluate the executed calculations, the results of the range calculations respecting the analysed transport aircraft have been compiled in a table, see page 54.

Altogether, the ranges of ten built aircraft have been re-calculated and compared with the statements of the aircraft manufacturers. Moreover, the corresponding data have also been elaborated for Configuration Scheme 1.

The table of results reveals that the calculated range data differ only slightly from the information of the manufacturers, barring three exceptions.

The average absolute difference, including the three somewhat more significant deviations, is 6.3%.

The more significant deviations are results of the calculations referring to the Lockheed L-100, de Havilland Buffalo and Airbus A300B aircraft. The maximum deviation is 12.5%.

Excluding these three results, the average absolute difference is only 3.9%.

For the three aircraft with the more significant calculation result deviations, a second range value or a second deviation in percentage numbers has been stated in the table (bottom line). These numbers are based on a different assumption for the hold fuel of the aircraft Lockheed L-100 and de Havilland Buffalo, whereas, for the Airbus A300B, they are based on a lower flight speed (speed for maximum flight time).

The additional calculations have been carried out in order to determine which assumptions the range calculations should be based on, in order to yield results which come closer to the statements of the manufacturers.

If the second calculation result is considered instead of the first one, the average absolute difference compared to the actual ranges for the ten built aircraft is only 4.6%.

Study Work Phase 10a

Re-calculation of the ferry ranges of ten built transport aircraft
and calculation of the ferry ranges for Configuration Scheme 1

Application of the new range formulas for transport aircraft

Cranfield University, School of Engineering

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: June 3rd, 2002

Signature: A. Mederer

Number of pages: 79

– study identification sheet –

Abstract

In this report, the ferry ranges of ten transport aircraft which have been built or are currently being operated shall be re-calculated, and these re-calculations shall be explained.

The explanations have been set up in a way that all calculations can be comprehended and the effect of individual initial data becomes apparent.

The calculations are based on formulas and fundamental data which are detailed in section 1.

The calculations respecting the individual aircraft have all been carried out following the same basic procedure, since the aim was to always use the same set of formulas.

The set of formulas used gives the following information:

Basic set of formulas

for conditions A and B:

- maximum range without payload, without reserves
- maximum range without payload, with reserves

for condition C:

- maximum range with payload and maximum fuel, with reserves
- maximum range without payload, with maximum fuel and with reserves

Extended set of formulas

for conditions A and B:

- range, based on maximum flight time without payload, without reserves
- range, based on maximum flight time without payload, with reserves

for condition C:

- range, based on maximum flight time, with payload and maximum fuel, with reserves
- range, based on maximum flight time without payload, with maximum fuel and with reserves

Formulas for calculating the parameters

for condition C:

- payload / maximum take-off weight for a given maximum range
- flying weight for a given maximum range, based on constant payload / maximum take-off weight and empty weight / maximum take-off weight values
- flying weight for a given maximum range, based on payload / maximum take-off weight = 0

In order to allow for the calculated ferry ranges of the ten built transport aircraft to be compared with the ferry ranges of Configuration Scheme 1, the corresponding range values of Configuration Scheme 1 have also been calculated for conditions A and B in this study .

These calculations have been carried out for Configuration Scheme 1, using the basic engines, and for Configuration Scheme 1, using the alternative engines.

The ferry ranges corresponding with the set of formulas and the ranges with payload and maximum fuel of the ten built transport aircraft, and the ferry ranges of Configuration Scheme 1 have been juxtaposed in a table for comparison purposes. In order to allow for the calculation results referring to the built aircraft to be evaluated, the differences between the calculated ranges and the actual ranges have been stated in percentage numbers in the table.

The difference between the calculated range and the actual range is shown both for the main comparison condition C and for the secondary comparison conditions A and B.

A more detailed description of the conditions A, B and C can be found on page 10.

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures and Systems.

Examination of the Calculation Results:

As was the case in the report on Study Work Phase 10, the results of the range calculations respecting the analysed transport aircraft have been compiled in a table.

Altogether, the ferry ranges and some of the maximum fuel ranges of ten built aircraft have been re-calculated and compared with the statements of the aircraft manufacturers. Moreover, the corresponding data have also been elaborated for Configuration Scheme 1.

The table of results contains three types of calculation results for the following conditions:

Results stated in the upper line for each aircraft type:

- A maximum take-off weight without payload and without reserves
- B maximum take-off weight without payload, but with reserves

Results stated in the lower line for each aircraft type:

- C payload and maximum fuel with maximum take-off weight, with reserves
- or
- no payload, maximum fuel with reduced or maximum take-off weight, with reserves

Moreover, the available data of the aircraft manufacturers have also been stated in the table for conditions A, B and C.

The calculated range results were compared with the data of the aircraft manufacturers for conditions B and C.

In three cases (Boeing 707-320C, Boeing 747F, Airbus A300B), the payload corresponding with the stated range was calculated, since the manufacturers of these aircraft do not state any payload.

In two cases (Lockheed L-100, M.D. DC-10, Srs 10), the take-off weight corresponding with the stated range was calculated, since the manufacturers of these aircraft do state the zero payload, but not the matching take-off weight.

The table of results reveals that the calculated range data for condition C of the remaining four aircraft differ only slightly from the information of the manufacturers. The average absolute difference is 2.5 %.

The calculated range results for conditions A and B are theoretical ranges, which only become achievable if the fuel tank volume of the respective aircraft is large enough to reach the maximum take-off weight without payload.

The deviation between the theoretically possible ferry ranges and the manufacturers' data vary from 17.6 % to 89,1 %, barring one special case. This special case is the Boeing 737, the maximum fuel range of which is almost equal to the maximum payload range.

Study Work Phase 11

Scaling the Basic Configurations

- Scaling Configuration Scheme 1
- Scaling Configuration Scheme 2
- Scaling Configuration Scheme 4
- Scaling Configuration Scheme 5

Theoretical Foundations and Scaling Results

Cranfield University, School of Engineering

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: April 22, 2003

Signature:

A. Mederer

Number of pages: 45

- study identification sheet -

Abstract

In this report, the scaling of the basic configuration schemes 1, 2, 4 and 5 shall be described and documented.

In the description, the theoretical foundations of the scaling method and the corresponding algebraical formulas shall first be stated in section 1.1.

The scaling method is based on the definition of an overall aircraft volume that is made up of 8 volume elements (also see Study Work Phase 2). The 8 volume elements can either be lined up or put together to form a cube that is then scaled on a larger or smaller overall aircraft volume.

Along with the theoretical foundations, it shall be shown how to derive the scaling factor for a desired maximum take-off weight and how this factor affects the wing load.

To allow for scaling a configuration scheme at random, the so-called scaling factor function shall be developed in section 1.2.

Section 1.3 will deal with the 3 useful scaling possibilities that have already been mentioned under Work Item 11 of the Research Programme.

Section 2 will show the actual scaling of the 4 basic configuration schemes.

The scaled configuration schemes or scaling drawings have been compiled in a separate folder for each basic configuration. For reasons of clarity, this report only includes the study identification sheets and index pages of those folders.

So far, there are 5 folders with scaled basic configuration schemes altogether. The first 4 folders belong to the basic configuration schemes 1, 2, 4 and 5; they form the scaling steps 1 and 2. Folder 5 belongs to the basic configuration schemes 1.4 and 1.5 which have been scaled in accordance with scaling step 2; it forms the so-called scaling step 3.

In addition to the 4 basic configuration schemes, the study also includes the configuration schemes 6, 7, 8, 9, 10 and 11 that have been developed on the basis of the 4 basic configuration schemes. Therefore, section 3 describes how to proceed when scaling the 6 other configurations.

Report sections 4, 5 and 6 deal with aerophysical values such as wing load, zero drag and flight performance data that can change due to the applied scaling method.

Only qualitative statements on the corresponding changes are made here.

However, if the flight performance data of the scaled basic configuration schemes are to be determined precisely, the computing programmes KONFPRINZ1A and KONFPRINZ1B that have been developed within the framework of this study can be used.

Section 7 describes what has to be considered when scaling the side views of the basic configuration schemes 1, 2, 4 and 5.

This scaling process is not shown in Study Work Phase 11. However, statements on how to proceed are made.

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures and Systems.

Study Work Phase 12

Flight and transport task
of large transport or cargo aeroplanes

Definition of corresponding mission profiles

Cranfield University, School of Engineering
Course: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 043009

Date: 06. 09. 2003

Signature: A. Mederer

Number of pages: 34

- Study identification sheet -

Overview

In study phase 12, the flight and transport task of large transport or cargo aeroplanes is investigated in detail.

First in section 1 payload/range diagrams for a sample aeroplane (configuration principle 1) are described, which were calculated with the computer program KONFPRINZ1B.

The program produces two different types of payload/range diagrams, namely for maximum range or maximum flight time.

The basic theoretical principles for these calculations are described in section 1.1.

Then in section 2 the dependency of the ranges on the flight altitude is described for the sample aeroplane (configuration principle 1), which was also calculated with the computer program KONFPRINZ1B.

As with the payload/range diagrams, there are two types of diagram for the dependency of the ranges on the flight altitude, again for maximum range or maximum flight time.

The basic theoretical principles of these calculations are described in section 2.1.

For a large transport or cargo aeroplane there exist flight restrictions concerning flight velocity and flight altitude, which essentially depend on the wave drag of the whole aeroplane and on the maximum thrust of the engines.

In section 3 these flight restrictions are discussed for the sample aeroplane (configuration principle 1).

Section 4 of the report deals with so-called basic mission profiles for large transport aeroplanes. With the computer programs KONFPRINZ1A and KONFPRINZ1B it is possible to quickly determine corresponding mission profiles.

Together the two calculation programs provide three different flight missions, the first two of which apply to the maximum range and the third for the maximum flight time.

For the sample aeroplane (configuration principle 1), drawings are provided for three basic mission profiles.

Section 5 of the report investigates how aeroplane containers used up to now are suited to the configuration principles 1, 1.1, 1.2 and 1.3.

This report does not claim to be complete or final.

It serves only as evidence of studies made as part of the study program

PhD Design, Structures and Systems.

Study Work Phase 14

Flight Characteristics of the Four Basic Configurations

Static and Dynamic Longitudinal Stability

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 043009

Created on: January 19th, 2004

Signature:

A. Mederer

Number of pages: 43

- study identification sheet -

Abstract

In Study Work Phase 14, formulas for significant flight-characteristic quantities concerning the static and dynamic longitudinal stability which are particularly suitable for designing large transport aircraft shall be developed first. Afterwards, calculations for configuration schemes 1, 2, 4 and 5 shall be carried out with these formulas.

In section 1, the term 'static longitudinal stability' shall be explained on the basis of appropriate formulas. Then it shall be shown how to create a formula expression for the so-called horizontal stabiliser volume which includes the position of the aircraft's centre of gravity in relation to the wing's centre of pressure as well as the aircraft's mass moment of inertia. With this formula for the horizontal stabiliser volume, the horizontal stabiliser for a random aircraft can easily be laid out in basic, also taking the longitudinal dynamics into consideration. The formula for the horizontal stabiliser volume can also be depicted as a layout diagram, see page 12.

In section 2, the dynamic longitudinal stability shall be described with the help of equation (1) for the oscillation of the angle of attack. This equation includes constants, as far as the resilience and attenuation of the oscillation is concerned, which are formed by the aircraft's configuration and flight parameters. Subsequently, it shall be demonstrated that equation (1) of the oscillation of the angle of attack can also be written in the form of equation (2) of the oscillation of the angle of attack. This equation includes only 'real' flight characteristic quantities as constants, i. e. the natural frequency ω_0 and the attenuation ϕ . Formula expressions for ω_0 and ϕ shall be given. Then it shall be demonstrated how to formulate an important connection between the natural frequency and the attenuation. Moreover, a formula for the horizontal stabiliser's angle of incidence shall be developed which takes the horizontal stabiliser volume and the position of the aircraft's centre of gravity in relation to the wing's centre of pressure into account. Since the downward wind of the wing can influence the longitudinal stability and the horizontal stabiliser's angle of incidence, a formula shall be created for this also.

In section 3, a calculation for the horizontal stabiliser's trimming angle shall be given, both without and with the downward wind of the wing. The basis of calculation for this is configuration scheme 1.

Section 4 deals with the constants included in equation (1) of the oscillation of the angle of attack respecting the use of a fully electrical control system. In this context, the constants for the resilience of the oscillation K_2 as well as for the attenuation of the oscillation K_1 shall be extended by the so-called control factors which represent the connection of the flight control system to the pitching moment generators. To be able to work out the extended constants of oscillation equation (1) for the configuration schemes, the corresponding constant formulas shall be given, along with appropriate explanations.

In sections 5 and 6, calculations of ω_0 and ϕ of the oscillation of the angle of attack for configuration schemes 1, 2, 4 and 5 shall be described in detail.

In section 7, the equation (3) of the track angle oscillation shall be stated in addition to section 2, and a simple formula for the natural frequency ω_0 of this oscillation shall be derived.

Section 8 will demonstrate corresponding calculations of ω_0 of the track angle oscillation for configuration schemes 1, 2, 4 and 5.

In section 9, the results of the calculations will be discussed with the help of result tables.

This report does not claim to be complete or final. Its purpose is to serve as a performance record within the framework of the study programme

PhD Design, Structures and Systems.

Discussion of the Calculation Results

1. On the Oscillation of the Angle of Attack

On pages 30 through 37, calculations for configuration schemes 1, 2, 4 and 5 have been shown. For these calculations, the formulas developed on pages 15 through 19 as well as 23 through 29 are used. All calculations have been written in a clearly understandable and verifiable way. The natural frequency and attenuation of the oscillation are determined for each configuration scheme. Since only configuration scheme 1 is stable in the basic layout (see Study Work Phase 3), control quantities of artificial stabilisation are taken into account in the calculations in order to achieve useful values for the flight characteristics ω_0 and ϕ . To make the characteristics values of the various configuration schemes comparable, the numerical values of the control quantities have largely been kept identical in the calculations. Only for configuration scheme 5 the numerical values of the control quantities have been enlarged by factor 10, because smaller values would not lead to the desired values for the flight characteristics quantities ω_0 and ϕ here.

On page 41, the calculated values for natural frequency and attenuation of the oscillation of the angle of attack have been entered in the upper table.

The following calculations have been carried out for configuration scheme 1 (CS1):

Determining the natural frequency and attenuation:

1. Without stabilising device and without attenuator
2. With stabilising device and without attenuator
3. Without stabilising device and with attenuator
4. With stabilising device and with attenuator

The following calculations have been carried out for configuration schemes 2, 4 und 5 (CS2, CS4 and CS5):

Determining the natural frequency and attenuation:

4. With stabilising device and with attenuator

Item 1 was not calculated because CS2, CS4 and CS5 do not work without a stability support. Item 2 was not calculated because CS2, CS4 and CS5 do work with a stability support, but an attenuation support is also required. Item 3 was not calculated because CS2, CS4 and CS5 do not work with an attenuation support only.

To be able to evaluate the numbers entered in the upper table for natural frequency ω_0 and attenuation ϕ , the corresponding set-points must be known.

Set-point for ω_0 of the α - oscillation : 2.2 1/s

Set-point for ϕ of the α - oscillation: 0.3 ÷ 1.0

From the upper table, it becomes clear that for CS1, case 3 meets the requirements.

In case 1, the attenuation is too low.

In case 2, the natural frequency is too high.

In case 4, the natural frequency is too high.

Moreover, the upper table shows that, of the principles examined in case 4, only CS2 meets the requirements approximately. For CS4 and CS5, the control quantities must be changed to achieve the upper set-points in the calculations. The control quantities have been enlarged by factor 10 for CS5 because the moment arm from the aircraft's centre of gravity to the vector nozzle is much smaller than the corresponding moment arm in the other configuration schemes.

2. On the Track Angle Oscillation

On page 41, the calculated values for the natural frequency of the track angle oscillation for configuration schemes 1, 2, 4 and 5 have been entered in the lower table.

For configuration scheme 1, the following applies in case 3 of the upper table:

$$\omega_0 - \text{oscillation of the angle of attack} / \omega_0 - \text{track angle oscillation} = 2.2860 / 0.05898 \approx 39$$

Study Work Phase 13

Which of the scaled basic designs best fulfils the mission values 12?

Differences in performance of the four basic designs with regard to task 12

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 043009

Date: 17.02.2004

Signature: A. Mederer

Number of pages: 9

- Study cover sheet -

Overview

Study phase 13 investigates which of the four basic configuration principles is the best in terms of transport capacity.

To determine this, a comparative basis or a basic transport mission is necessary, which contains the two ranges R_{Tmax} and R_{max} in addition to the take-off and landing field length as well as climb and descent.

R_{Tmax} = Range for maximum flight time

R_{max} = maximum range

These ranges can now be calculated for every basic configuration principle, which was done in study phase 8 with provisional C_{wo} values and in Calculations no. 1 with exactly calculated C_{wo} values for the four basic designs.

In order to determine the best configuration principle in terms of range, the range values R_{Tmax} and R_{max} of a basic configuration principle are applied to the relevant range values of the selected basic transport mission.

Section 1 states which basic transport mission is to be used as the comparative basis and lists the corresponding values for R_{Tmax} and R_{max} .

Section 2 presents the values for R_{Tmax} and R_{max} for the individual configuration principles based on the results table of study phase 8. To enable a comparison to be made, the range values of the selected basic transport mission and those of the configuration principles must be for the same flight altitude.

Then a range diagram is shown on page 6, in which the values for R_{Tmax} and R_{max} for the four basic configuration principles are entered. The data shown here correspond to those of Calculations no. 1.

The range diagrams are discussed in section 3.

A simple rule is given for the difference between maximum range R_{max} and range with maximum flight time R_{Tmax} .

In addition, results of the range comparison of configuration principles 1, 2, 4 and 5 are presented.

This report does not claim to be complete or final.

It serves only as evidence of studies made as part of the study program

PhD Design, Structures and Systems.

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DRAWING FILE 1

of Study Work Phase 8

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Configuration scheme 1, side and front view, DIN A1

Data sheets for configuration scheme 1, 4 sheets, DIN A4

Description sheets for configuration scheme 1, 2 sheets, DIN A4

Sheet of symbols for configuration scheme 1, DIN A4

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: September 8th, 2000

DRAWING FILE 2

of Study Work Phase 8

Contents:

Configuration scheme 2, top view, DIN A1, *DIN A4*

Configuration scheme 2, side and front view, DIN A1, *DIN A4*

Data sheets for configuration scheme 2, 4 sheets, DIN A4

Description sheets for configuration scheme 2, 3 sheets, DIN A4

Sheet of symbols for configuration scheme 2, DIN A4

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: *October 31st, 2000*

DRAWING FILE 3

of Study Work Phase 8

Contents:

Configuration scheme 4, top view, DIN A1, *DIN A4*

Configuration scheme 4, side and front view, DIN A1, *DIN A4*

Data sheets for configuration scheme 4, 4 sheets, DIN A4

Description sheets for configuration scheme 4, 3 sheets, DIN A4

Sheet of symbols for configuration scheme 4, DIN A4

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: *January 26th, 2001*

DRAWING FILE 4

of Study Work Phase 8

Contents:

Configuration scheme 5, top view, DIN A1, *DIN A4*

Configuration scheme 5, side and front view, DIN A1, *DIN A4*

Data sheets for configuration scheme 5, 4 sheets, DIN A4

Description sheets for configuration scheme 5, 3 sheets, DIN A4

Sheet of symbols for configuration scheme 5, DIN A4

Cranfield University, College of Aeronautics

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: *February 14th, 2001*

POSTER ROLL 1

of Study Work Phase 8

Contents:

Configuration scheme 1, top view (coloured), DIN A1, DIN A4
Configuration scheme 1, side and front view (coloured), DIN A1, DIN A4
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of top view (coloured), side and front view (coloured)
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of top view (coloured), side and front view (coloured)

Cranfield University, College of Aeronautics
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Created on: April 24th, 2001

POSTER ROLL 2

of Study Work Phase 8

Contents:

Configuration scheme 2, top view (coloured), DIN A1, DIN A4

Configuration scheme 2, side and front view (coloured), DIN A1, DIN A4

Description sheet for configuration scheme 2, DIN A4

of top view (coloured), side and front view (coloured)

Designations sheet for configuration scheme 2, DIN A4

of top view (coloured), side and front view (coloured)

Cranfield University, *School of Engineering*

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 952943

Created on: *March 30th, 2002*

POSTER ROLL 3

of Study Work Phase 8

Contents:

Configuration scheme 4, top view (coloured), DIN A1, DIN A4

Configuration scheme 4, side and front view (coloured), DIN A1, DIN A4

Description sheet for configuration scheme 4, DIN A4

of top view (coloured), side and front view (coloured)

Designations sheet for configuration scheme 4, DIN A4

of top view (coloured), side and front view (coloured)

Cranfield University, *School of Engineering*

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 043009

Created on: *July 17th, 2003*

POSTER ROLL 4

of Study Work Phase 8

Contents:

Configuration scheme 5, top view (coloured), DIN A1, DIN A4

Configuration scheme 5, side and front view (coloured), DIN A1, DIN A4

Description sheet for configuration scheme 5, DIN A4

of top view (coloured), side and front view (coloured)

Designations sheet for configuration scheme 5, DIN A4

of top view (coloured), side and front view (coloured)

Cranfield University, *School of Engineering*

Course of studies: PhD Design, Structures and Systems

Student: Andreas Mederer

Ref.: 043009

Created on: *October 15th, 2003*

Scaling of Configuration Principle 1, step no. 1 and 2

Section of Study Work Phase 11

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Date: 22. 07. 2002

Signature: A. Mederer

Number of pages: 8

- study identification sheet -

Contents:

Scaling of Configuration principle 1, different payload:

Max TO-weight 200 t, payload 50 t (basic aeroplane)

Max TO-weight 400 t, payload 100 t

Max TO-weight 600 t, payload 150 t

Max TO-weight 800 t, payload 200 t

Scaling of Configuration principle 1, constant payload, different fuel-weight:

Max TO-weight 200 t, payload 50 t, fuel-weight 50 t (basic aeroplane)

Max TO-weight 225 t, payload 50 t, fuel-weight 75 t

Max TO-weight 175 t, payload 50 t, fuel-weight 25 t

Scaling factor for different Max TO-weight, Configuration principle 1:

Diagram $K_{Skal} = f(G_A)$

Scaling of Configuration Principle 2, step no. 1 and 2

Section of Study Work Phase 11

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Date: 18. 11. 2002

Signature:

A. Mederer

Number of pages: 8

- study identification sheet -

Contents:

Scaling of Configuration principle 2, different payload:

Max TO-weight 200 t, payload 50 t (basic aeroplane)

Max TO-weight 400 t, payload 100 t

Max TO-weight 600 t, payload 150 t

Max TO-weight 800 t, payload 200 t

Scaling of Configuration principle 2, constant payload, different fuel-weight:

Max TO-weight 200 t, payload 50 t, fuel-weight 50 t (basic aeroplane)

Max TO-weight 225 t, payload 50 t, fuel-weight 75 t

Max TO-weight 175 t, payload 50 t, fuel-weight 25 t

Scaling factor for different Max TO-weight, Configuration principle 2:

Diagram $K_{Skal} = f(G_A)$

Scaling of Configuration Principle 4, step no. 1 and 2

Section of Study Work Phase 11

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Date: 09. 12. 2002

Signature: A. Mederer

Number of pages: 8

- study identification sheet -

Contents:

Scaling of Configuration principle 4, different payload:

Max TO-weight 250 t, payload 50 t (basic aeroplane)

Max TO-weight 500 t, payload 100 t

Max TO-weight 750 t, payload 150 t

Max TO-weight 1000 t, payload 200 t

Scaling of Configuration principle 4, constant payload, different fuel-weight:

Max TO-weight 250 t, payload 50 t, fuel-weight 50 t (basic aeroplane)

Max TO-weight 275 t, payload 50 t, fuel-weight 75 t

Max TO-weight 225 t, payload 50 t, fuel-weight 25 t

Scaling factor for different Max TO-weight, Configuration principle 4:

Diagram $K_{Skal} = f(G_A)$

Scaling of Configuration Principle 5, step no. 1 and 2

Section of Study Work Phase 11

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Date: 21. 01. 2003

Signature: A. Mederer

Number of pages: 8

- study identification sheet -

Contents:

Scaling of Configuration principle 5, different payload:

Max TO-weight 200 t, payload 50 t (basic aeroplane)

Max TO-weight 400 t, payload 100 t

Max TO-weight 600 t, payload 150 t

Max TO-weight 800 t, payload 200 t

Scaling of Configuration principle 5, constant payload, different fuel-weight:

Max TO-weight 200 t, payload 50 t, fuel-weight 50 t (basic aeroplane)

Max TO-weight 225 t, payload 50 t, fuel-weight 75 t

Max TO-weight 175 t, payload 50 t, fuel-weight 25 t

Scaling factor for different Max TO-weight, Configuration principle 5:

Diagram $K_{Skat} = f(G_A)$

Scaling of Configuration Principle 1, step no. 3

Section of Study Work Phase 11

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Date: 25. 02. 2003

Signature: A. Mederer

Number of pages: 11

- study identification sheet -

Contents:

Scaling of Configuration principle 1.4, different payload, increased fuel-weight:

Max TO-weight 225 t, payload 50 t, fuel weight 75 t (basic aeroplane)

Max TO-weight 450 t, payload 100 t, fuel weight 150 t

Max TO-weight 675 t, payload 150 t, fuel weight 225 t

Max TO-weight 900 t, payload 200 t, fuel weight 300 t

Scaling of Configuration principle 1.5, different payload, decreased fuel-weight:

Max TO-weight 175 t, payload 50 t, fuel-weight 25 t (basic aeroplane)

Max TO-weight 350 t, payload 100 t, fuel-weight 50 t

Max TO-weight 525 t, payload 150 t, fuel-weight 75 t

Max TO-weight 700 t, payload 200 t, fuel-weight 100 t

Scaling factor for different Max TO-weight, Configuration principle 1.4:

Diagram $K_{Skal} = f(G_A)$

Scaling factor for different Max TO-weight, Configuration principle 1.5:

Diagram $K_{Skal} = f(G_A)$

**Basic Mission profiles for large Transport aeroplanes
as foundation for performance comparisons**

Section of Study Work Phase 12

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 043009

Date: 29. 08. 2003

Signature: A. Mederer

Number of pages: 4

Study identification sheet

Calculations no. 1

with the computer programs no. 1, 2, 3, 4 and 5

or CW02TAB, CW02TAB2, CW02TAB4, CW02TAB5 and KONFPRINZ1

**Cranfield University, School of Engineering
Studiengang: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943**

Date: 18. 01. 2002

Signature: A. Mederer

Number of pages: 15

Calculations:

Zero drag calculation for Airbus A300B

Zero drag calculation for configuration principle 1

Zero drag calculation for configuration principle 2

Zero drag calculation for configuration principle 4

Zero drag calculation for configuration principle 5

Range calculations for Airbus A300B

Range calculations for configuration principle 1

Range calculations for configuration principle 2

Range calculations for configuration principle 4

Range calculations for configuration principle 5

Calculations no. 2

with the computer programs no. 1 and 6

or CW02TAB and KONFPRINZ1A

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Date: 25. 02. 2002

Signature: A. Mederer

Number of pages: 16

Calculations:

Zero drag calculation for Lockheed C-5A, Galaxy, sheet no. 1

Zero drag calculation for Lockheed C-5A, Galaxy, sheet no. 2

Range calculations for Lockheed C-5A, Galaxy

Range calculations for Boeing 737-200C

Range calculations for Boeing 707-320C, sheet no. 1

Range calculations for Boeing 707-320C, sheet no. 2

Range calculations for Boeing 747F

Range calculations for Lockheed L-1011

Range calculations for Lockheed L-100

Range calculations for de Havilland Buffalo

Range calculations for M.D. DC-9, Srs 30

Range calculations for Airbus A300B

Range calculations for M.D. DC-10, Srs 10

Range calculations for Configuration Principle 1, using the Basic Engines

Range calculations for Configuration Principle 1, using the Alternative Engines

Calculations no. 3

with the computer program no. 1
or CW02TAB

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Date: 17. 03. 2002

Signature: A. Mederer

Number of pages: 10

Calculations identification sheet

Calculations:

Zero drag calculation for Airbus A300B, sheet no. 1

Zero drag calculation for Airbus A300B, sheet no. 2

Zero drag calculation for M.D. DC-10, Srs 30, sheet no. 1

Zero drag calculation for M.D. DC-10, Srs 30, sheet no. 2

Zero drag calculation for Lockheed C-5A, Galaxy, sheet no. 1

Zero drag calculation for Lockheed C-5A, Galaxy, sheet no. 2

Zero drag calculation for Lockheed L 100-30, sheet no. 1

Zero drag calculation for Lockheed L 100-30, sheet no. 2

Comparison table:

Zero drag values with approximation formulas

and

Zero drag values with spreadsheets

Reference data:

Jane's

All the World's Aircraft 1971-72

Calculations no. 4

with the computer program no. 6
or KONFPRINZ1A

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Date: 21. 03. 2002

Signature: A. Mederer

Number of pages: 36

Calculations identification sheet

Calculations

	page
Calculations A	2 to 15
Calculations B	16 to 26
Calculations C	27 to 35

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Calculations A:

Zero payload

Ferry range calculations for Lockheed C-5A, Galaxy, Max T-O weight, without reserves

Ferry range calculations for Boeing 737-200C, Max T-O weight, without reserves

Ferry range calculations for Boeing 707-320C, Max T-O weight, without reserves

Ferry range calculations for Boeing 707-320C, average cruising weight, without reserves

Ferry range calculations for Boeing 747F, Max T-O weight, without reserves

Ferry range calculations for Lockheed L-1011, Max T-O weight, without reserves

Ferry range calculations for Lockheed L-100, Max T-O weight, without reserves

Ferry range calculations for de Havilland Buffalo, Max T-O weight, without reserves

Ferry range calculations for M.D. DC-9, Srs 30, Max T-O weight, without reserves

Ferry range calculations for Airbus A300B, Max T-O weight, without reserves

Ferry range calculations for M.D. DC-10, Srs 10, Max T-O weight, without reserves

Ferry range calculations for Configuration principle 1, using the Basic engines,
Max T-O weight, without reserves

Ferry range calculations for Configuration principle 1, using the Alternative engines,
Max T-O weight, without reserves

Calulations B:

Zero payload

Ferry range calculations for Boeing 737-200C, Max T-O weight, with reserves

Ferry range calculations for Boeing 747F, Max T-O weight, with reserves

Ferry range calculations for Lockheed L-1011, Max T-O weight, with reserves

Ferry range calculations for Lockheed L-100, Max T-O weight, with reserves

Ferry range calculations for de Havilland Buffalo, Max T-O weight, with reserves

Ferry range calculations for M.D. DC-9, Srs 30, Max T-O weight, with reserves

Ferry range calculations for Airbus A300B, Max T-O weight, with reserves

Ferry range calculations for M.D. DC-10, Srs 10, Max T-O weight, with reserves

Ferry range calculations for Configuration principle 1, using the Basic engines,
Max T-O weight, with reserves

Ferry range calculations for Configuration principle 1, using the Alternative engines,
Max T-O weight, with reserves

Calculations C:

Max fuel

Ferry range calculations for Boeing 737-200C, payload, with reserves

Ferry range calculations for Boeing 707-320C, payload calculated, with reserves

Ferry range calculations for Boeing 747F, payload calculated, with reserves

Ferry range calculations for Lockheed L-1011, payload, with reserves

Ferry range calculations for Lockheed L-100, Zero payload, with reserves

Ferry range calculations for de Havilland Buffalo, payload, with reserves

Ferry range calculations for Airbus A300B, payload calculated, with reserves

Ferry range calculations for M.D. DC-10, Srs 10, Zero payload, with reserves

Calculations no. 5

with the computer program no. 7
or KONFPRINZ1B

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Date: 06. 05. 2002

Signature: A. Mederer

Number of pages: 15

Calculations identification sheet

Calculations:

Speed calculations for Lockheed C-5A, Galaxy

Speed calculations for Boeing 737-200C

Speed calculations for Boeing 707-320C

Speed calculations for Boeing 747F

Speed calculations for Lockheed L-1011, sheet no. 1

Speed calculations for Lockheed L-1011, sheet no. 2

Speed calculations for Lockheed L-100

Speed calculations for de Havilland Buffalo

Speed calculations for M.D. DC-9, Srs 30

Speed calculations for Airbus A300B

Speed calculations for M.D. DC-10, Srs 10

Speed calculations for Configuration Principle 1, using the Basic Engines

Speed calculations for Configuration Principle 1, using the Alternative Engines

Calculations no. 6

with the computer program no. 8
ROLLSTRECKE

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Date: 24. 03. 2003

Signature:

A. Mederer

Number of pages: 9

Calculations identification sheet

Calculations:

Configuration principle 1, Rollstrecke

Calculations for: TAKE-OFF

Calculations for: LANDING

Configuration principle 2, Rollstrecke

Calculations for: TAKE-OFF

Calculations for: LANDING

Configuration principle 4, Rollstrecke

Calculations for: TAKE-OFF

Calculations for: LANDING

Configuration principle 5, Rollstrecke

Calculations for: TAKE-OFF

Calculations for: LANDING

Calculations no. 7

**with the computer program no. 7
or KONFPRINZ1B**

Cranfield University, School of Engineering
Course of studies: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 043009

Date: 15. 06. 2003

Signature: A. Mederer

Number of pages: 37

Calculations identification sheet

Calculations for Configuration principle 1:

Calculations $R_{\max} = f(G_N)$ and $R_{T\max} = f(G_N)$:

$H = 7 \text{ km}$

Categories a, b and c

Calculation no. 1

Calculation no. 2

Calculation no. 3

Calculation no. 4

Calculation no. 5

Calculation no. 6

Calculation no. 7

Calculation no. 8

Calculation no. 9

Calculation no. 10

Calculation no. 11

Calculations $R_{\max} = f(H)$ and $R_{T\max} = f(H)$:

$G_{N\max}$

Categories a, b and c

Calculation no. 1₁

Calculation no. 1₂

Calculation no. 1₃

Calculation no. 1₄

Calculation no. 4₁

Calculation no. 4₂

Calculation no. 4₃

Calculation no. 4₄

Calculation no. 7₁

Calculation no. 7₂

Calculation no. 7₃

Calculation no. 7₄

Calculation no. 7_{5,1}

Calculation no. 7_{5,2}

Additional Calculations $R_{\max} = f(H)$ and $R_{T\max} = f(H)$:

$G_{N\max}$

Category c

Calculation no. 7₆

Calculation no. 7₇

Calculation no. 7₈

Calculation no. 7₉

Calculation no. 7_{10,1}

Calculation no. 7_{10,2}

Calculation no. 7₁₁

Computer-Programm Nr. 1

CW02TAB

Cranfield University, College of Aeronautics
Studiengang: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Datum: 16. 07. 2001

Unterschrift: A. Mederer

Seitenzahl: 7

dazu 1 Diskette

Programm-Kennblatt

Computer-Programm Nr. 2

CW02TAB2

Cranfield University, College of Aeronautics
Studiengang: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Datum: 04. 09. 2001

Unterschrift:

A. Mederer

Seitenzahl: 5

dazu 1 Diskette

Programm-Kennblatt

Computer-Programm Nr. 3

CW02TAB4

Cranfield University, College of Aeronautics
Studiengang: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Datum: 04. 09. 2001

Unterschrift: A. Mederer

Seitenzahl: 6

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Programm-Kennblatt

Computer-Programm Nr. 4

CW02TAB5

Cranfield University, College of Aeronautics
Studiengang: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Datum: 04. 09. 2001

Unterschrift: A. Mederer

Seitenzahl: 6

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Programm-Kennblatt

Computer-Programm Nr. 5

KONFPRINZI

Cranfield University, School of Engineering
Studiengang: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Datum: 17. 12. 2001

Unterschrift: A. Mederer

Seitenzahl: 10

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Programm-Kennblatt

Computer-Programm Nr. 6

KONFPRINZ1A

Cranfield University, School of Engineering
Studiengang: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Datum: 25. 01. 2002

Unterschrift: A. Mederer

Seitenzahl: 9

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Programm-Kennblatt

Computer-Programm Nr. 7

KONFPRINZ1B

Cranfield University, School of Engineering
Studiengang: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Datum: 02. 05. 2002

Unterschrift: A. Mederer

Seitenzahl: 11

dazu 1 Diskette

Programm-Kennblatt

Computer-Programm Nr. 8

ROLLSTRECKE

Cranfield University, School of Engineering
Studiengang: PhD Design, Structures and Systems
Student: Andreas Mederer
Ref.: 952943

Datum: 09. 01. 2003

Unterschrift: A. Mederer

Seitenzahl: 9

dazu 1 Diskette

Programm-Kennblatt

Designations:

G_A (t)	Maximum take-off weight of the aircraft
F (m ²)	Reference wing area of the aircraft
b_F (m)	Wing span
Λ_F	Wing aspect ratio
l_R (m)	Length of the aircraft's overall fuselage
b_R (m)	Width of the aircraft's overall fuselage
D_E (m)	Mean diameter of the engine's overall airflow inlet
n	Multiple of the maximum take-off weight of the non-scaled aircraft Configuration principle 1
K_{Skal}	Scaling factor
G_A/F (t/m ²)	Wing load of the aircraft
$(G_A/F)_{Skal}$ (t/m ²)	Wing load of the generally scaled aircraft Configuration principle 1
$b_{F, Skal, 1}$ (m)	Wing span of the generally scaled aircraft, Step 1 Configuration principle 1
$b_{F, Skal, 2}$ (m)	Wing span of the generally scaled aircraft, Step 2 Configuration principle 1
$l_{R, Skal}$ (m)	Length of the scaled aircraft's overall fuselage Configuration principle 1
$b_{R, Skal}$ (m)	Width of the scaled aircraft's overall fuselage Configuration principle 1
$D_{E, Skal}$ (m)	Mean diameter of the scaled engine's overall airflow inlet Configuration principle 1

Calculations for:

Lockheed C-5A, Galaxy
Boeing 747F
Airbus A380F
ECOLIFTER, 200 t payload version
F-02, Civil freight aircraft

Lockheed C-5A, Galaxy:

Parameter: $G_A = 330,2 \text{ t}$
 $F = 576,0 \text{ m}^2$
 $b_F = 67,88 \text{ m}$
 $\Lambda_F = 8,0$
 $l_R = 70,29 \text{ m}$
 $b_R = (1,13 + 1,27)/2 \cdot 6,668 = 8,0016 \text{ m}$
 $D_E = 2,54 \text{ m}$

$$n = 330,2/200 = 1,651$$

$$K_{\text{Skal}} = \sqrt[3]{1,651} = 1,1819$$

$$G_A/F = 330,2/576,0 = 0,57326 \text{ t/m}^2$$

$$(G_A/F)_{\text{Skal}} = \underline{0,5} \cdot 1,1819 = 0,59095 \text{ t/m}^2 \quad (+3,1 \%)$$

$$b_{F, \text{Skal}, 1} = \underline{55,39} \cdot 1,1819 = 65,4654 \text{ m}$$

$$b_{F, \text{Skal}, 2} = 65,4654 \cdot \sqrt{8,0/\underline{7,67}} = 66,859 \text{ m} \quad (-1,5 \%)$$

$$l_{R, \text{Skal}} = \underline{57,5} \cdot 1,1819 = 67,959 \text{ m} \quad (-3,3 \%)$$

$$b_{R, \text{Skal}} = \underline{7,0} \cdot 1,1819 = 8,273 \text{ m} \quad (+3,4 \%)$$

$$D_{E, \text{Skal}} = \underline{2,76}/\sqrt{2} \cdot 1,1819 = 2,307 \text{ m} \quad (-9,2 \%)$$

Boeing 747F:

Parameter: $G_A = 351,54 \text{ t}$ (B, C, F)

$$F = 511,0 \text{ m}^2$$

$$b_F = 59,64 \text{ m}$$

$$\Lambda_F = 6,9607$$

$$l_R = 68,63 \text{ m}$$

$$b_R = (1,0 + 1,05)/2 \cdot 7,5005 = 7,6880 \text{ m}$$

$$D_E = 2,428 \text{ m}$$

$$n = 351,54/200 = 1,7577$$

$$K_{\text{Skal}} = \sqrt[3]{1,7577} = 1,2068$$

$$G_A/F = 351,54/511,0 = 0,68795 \text{ t/m}^2$$

$$(G_A/F)_{\text{Skal}} = \underline{0,5} \cdot 1,2068 = 0,6034 \text{ t/m}^2 \quad (-12,3 \%)$$

$$b_{F, \text{Skal}, 1} = \underline{55,39} \cdot 1,2068 = 66,8447 \text{ m}$$

$$b_{F, \text{Skal}, 2} = 66,8447 \cdot \sqrt{6,9607/\underline{7,67}} = 63,679 \text{ m} \quad (+6,8 \%)$$

$$l_{R, \text{Skal}} = \underline{57,5} \cdot 1,2068 = 69,391 \text{ m} \quad (+1,1 \%)$$

$$b_{R, \text{Skal}} = \underline{7,0} \cdot 1,2068 = 8,448 \text{ m} \quad (+9,9 \%)$$

$$D_{E, \text{Skal}} = \underline{2,76}/\sqrt{2} \cdot 1,2068 = 2,355 \text{ m} \quad (-3,0 \%)$$

Airbus A380F:

Parameter: $G_A = 590 \text{ t}$
 $F = 845 \text{ m}^2$
 $b_F = 79,80 \text{ m}$
 $\Lambda_F = 7,5361$
 $l_R = 73,0 \text{ m}$ (overall)
 $b_R = (7,14 + 8,47)/2 = 7,805 \text{ m}$
 $D_E = 3,486 \text{ m}$

$$n = 590/200 = 2,950$$

$$K_{\text{Skal}} = \sqrt[3]{2,95} = 1,4341$$

$$G_A/F = 590/845 = 0,69822 \text{ t/m}^2$$

$$(G_A/F)_{\text{Skal}} = \underline{0,5} \cdot 1,4341 = 0,71705 \text{ t/m}^2 \quad (+2,7 \%)$$

$$b_{F, \text{Skal}, 1} = \underline{55,39} \cdot 1,4341 = 79,4348 \text{ m}$$

$$b_{F, \text{Skal}, 2} = 79,4348 \cdot \sqrt{7,5361/\underline{7,67}} = 78,738 \text{ m} \quad (-1,3 \%)$$

$$l_{R, \text{Skal}} = \underline{57,5} \cdot 1,4341 = 82,461 \text{ m} \quad (+13,0 \%)$$

$$b_{R, \text{Skal}} = \underline{7,0} \cdot 1,4341 = 10,039 \text{ m} \quad (+28,6 \%)$$

$$D_{E, \text{Skal}} = \underline{2,76}/\sqrt{2} \cdot 1,4341 = 2,799 \text{ m} \quad (-19,7 \%)$$

ECOLIFTER, 200 t payload version:

Parameter: $G_A = 530 \text{ t}$
 $F = 900 \text{ m}^2$
 $b_F = 85,0 \text{ m}$
 $\Lambda_F = 8,028$
 $l_R = 78,0 \text{ m}$
 $b_R = (1,18 + 1,57)/2 \cdot 6,7621 = 9,298 \text{ m}$
 $D_E = 2,834 \text{ m}$

$$n = 530/200 = 2,65$$

$$K_{\text{Skal}} = \sqrt[3]{2,65} = 1,3838$$

$$G_A/F = 530/900 = 0,58889 \text{ t/m}^2$$

$$(G_A/F)_{\text{Skal}} = \underline{0,5} \cdot 1,3838 = 0,6919 \text{ t/m}^2 \quad (+17,5 \%)$$

$$b_{F, \text{Skal}, 1} = \underline{55,39} \cdot 1,3838 = 76,649 \text{ m}$$

$$b_{F, \text{Skal}, 2} = 76,649 \cdot \sqrt{8,028/\underline{7,67}} = 78,417 \text{ m} \quad (-7,7 \%)$$

$$l_{R, \text{Skal}} = \underline{57,5} \cdot 1,3838 = 79,569 \text{ m} \quad (+2,0 \%)$$

$$b_{R, \text{Skal}} = \underline{7,0} \cdot 1,3838 = 9,687 \text{ m} \quad (+4,2 \%)$$

$$D_{E, \text{Skal}} = \underline{2,76}/\sqrt{2} \cdot 1,3838 = 2,701 \text{ m} \quad (-4,7 \%)$$

F-02, Civil freight aircraft:

Parameter: $G_A = 116,5 \text{ t}$
 $F = 204,33 \text{ m}^2$
 $b_F = 47,41 \text{ m}$
 $\Lambda_F = 11,0$
 $l_R = 41,0 \text{ m}$ (overall)
 $b_R = 5,0 \text{ m}$
 $D_E = 1,699 \text{ m}$

$$n = 116,5/200 = 0,5825$$

$$K_{\text{Skal}} = \sqrt[3]{0,5825} = 0,8352$$

$$G_A/F = 116,5/204,33 = 0,57016 \text{ t/m}^2$$

$$(G_A/F)_{\text{Skal}} = \underline{0,5} \cdot 0,8352 = 0,4176 \text{ t/m}^2 \quad (-27,7 \%)$$

$$b_{F, \text{Skal}, 1} = \underline{55,39} \cdot 0,8352 = 46,262 \text{ m} \quad (-0,2 \%)$$

$$b_{F, \text{Skal}, 2} = 46,262 \cdot \sqrt{11,0/\underline{7,67}} = 55,402 \text{ m} \quad (+16,9 \%)$$

$$l_{R, \text{Skal}} = \underline{57,5} \cdot 0,8352 = 48,024 \text{ m} \quad (+17,1 \%)$$

$$b_{R, \text{Skal}} = \underline{7,0} \cdot 0,8352 = 5,846 \text{ m} \quad (+16,9 \%)$$

$$D_{E, \text{Skal}} = \underline{2,76/\sqrt{2}} \cdot 0,8352 = 1,630 \text{ m} \quad (-4,1 \%)$$

APPENDIX B

CRANFIELD UNIVERSITY

A. MEDERER

**THE DEVELOPMENT OF A DESIGN METHODOLOGY
FOR LARGE CARGO AIRCRAFT**

SCHOOL OF ENGINEERING

PhD THESIS

CRANFIELD UNIVERSITY

SCHOOL OF ENGINEERING

PhD THESIS

Academic Year 2007/2008

A. MEDERER

**The Development of a Design Methodology
For Large Cargo Aircraft**

Supervisor:

J. P. Fielding

November 2008

**This thesis is submitted in partial fulfilment of the requirements
for the degree of PhD**

LIST OF SYMBOLS

used in the "PhD Thesis Documents" of File 1 and File 2

Key

$W_{\max} \text{ (t)}$	max take-off weight
$W_E \text{ (t)}$	operational weight empty (with crew)
$W_{\text{Pay}} \text{ (t)}$	weight of payload
$W_{\text{Fuel}} \text{ (t)}$	weight of fuel
$f \cdot V \text{ (lb/km)}$	consumption per kilometre
$R \text{ (km); (int miles)}$	range
$f \cdot F \text{ (lb/lb} \cdot \text{h)} = \text{SFC}$	specific fuel consumption
$F \text{ (lb); (t)}$	thrust of the engines
$V \text{ (km/h); (int miles/h)}$	flight speed
$D \text{ (t)}$	flight drag of the aircraft
$(C_D/C_L)_{\text{opt}} \text{ (-)}$	optimum reciprocal lift/drag ratio
$C_{D0} \text{ (-)}$	coefficient of the lift-independent drag of the aircraft
$k \text{ (-)}$	$1/\pi \cdot A$
$A \text{ (-)}$	wing aspect ratio
$T \text{ (h)}$	flight time until the entire fuel has been used up
$k_E \text{ (-)}$	weight empty factor
$k_{\text{Pay}} \text{ (-)}$	payload factor
$k_{\text{Fuel}} \text{ (-)}$	fuel factor
$W_{\text{Pay, max}} \text{ (t)}$	max payload weight
$W_{\text{Pay, min}} \text{ (t)}$	minimum payload weight = reserve fuel weight
(quotient)	constant value

Key:

$h_0^3 \text{ (ft}^3\text{)}$	original volume of the payload
$W_{\text{Pay}} \text{ (t)}$	maximum weight of the payload
$W_{\text{spec}} \text{ (t/ft}^3\text{)}$	specific gravity of the payload
$h_0 \text{ (ft)}$	height of the original cubic cargo compartment
$h \text{ (ft)}$	height or width of the cargo compartment
$l \text{ (ft)}$	length of the cargo compartment
$h/l \text{ (-)} = k$	aspect ratio number of the cargo compartment
$h^3 \text{ (ft}^3\text{)}$	h^3
$l^3 \text{ (ft}^3\text{)}$	l^3
$W_{\text{max}} \text{ (t)}$	maximum take-off weight
$W_h \text{ (t)}$	weight of one aircraft cell (8 cells)
$W_{\text{Fuel}} \text{ (t)}$	weight of the fuel
$W_{\text{spec, Fuel}} \text{ (t/ft}^3\text{)}$	specific gravity of the fuel
$h_0^3, \text{ Aeroplane (ft}^3\text{)}$	overall aircraft volume according to definition
$W_E \text{ (t)}$	aircraft weight empty
$(h/l)_{\text{Aeroplane}} \text{ (-)} = k_{\text{Aeroplane}}$	aspect ratio number of the overall aircraft cargo compartment
$h_0, \text{ Aeroplane (ft)}$	height or width of overall aircraft original cargo compartment
$h_{\text{Aeroplane}} \text{ (ft)}$	height or width of overall aircraft cargo compartment
$l_{\text{Aeroplane}} \text{ (ft)}$	length of the overall aircraft cargo compartment

Key

W_{Pay} (t)	weight of payload
W_{max} (t)	max take-off weight
$C_{L\text{max}}$ (-)	max lift coefficient of the wing
q_{min} (lb/ft ²)	dynamic pressure with $C_{L\text{opt}}$ on the wing $C_{L\text{max}}$
S (ft ²); (m ²)	wing reference area
$C_{L\text{opt}}$ (-)	optimum lift coefficient of the wing
q_{opt} (lb/ft ²)	dynamic pressure with $C_{L\text{opt}}$ on the wing
q (lb/ft ²)	dynamic pressure during flight
V (ft/s); (int miles/h)	flight speed
ρ (lb · s ² /ft ⁴)	atmospheric density
V_{opt} (ft/s); (int miles/h)	flight speed with $C_{L\text{opt}}$ on the wing
C_{D0} (-)	coefficient of the zero drag of the aircraft
k (-)	$1/\pi \cdot A_S$
A_S (-)	aspect ratio of the wing
V_{min} (ft/s); (int miles/h)	flight speed with $C_{L\text{opt}}$ on the wing $C_{L\text{max}}$
W_{max}/S (lb/ft ²); (t/ft ²)	wing load of the aircraft
$V_{\text{opt, 7km}}$ (ft/s); (int miles/h)	flight speed with $C_{L\text{opt}}$ on the wing in an altitude of 7 km
$\rho_{7\text{km}}$ (lb · s ² /ft ⁴)	atmospheric density in an altitude of 7 km
b_S (ft)	wing span
λ_S (-)	taper ratio or span-chord ratio of the wing
c_{is} (ft)	wing depth outside
c_{is} (ft)	wing depth inside
h (ft)	height of the aircraft's overall cargo compartment
h^3 (ft ³)	volume of a cubical cargo compartment cubicle

$\bar{V}_0 (-)$	volume coefficient due to horizontal stabiliser
$l_{s,s}(\text{ft})$	moment arm of the horizontal stabiliser
$c(\text{ft})$	depth of the wing at the point of the wing area's centre of gravity
$S_s(\text{ft}^2)$	reference area of the horizontal stabiliser
$\phi_s(\text{degrees})$	sweep angle of the wing in the centre of the wing area
$\phi_{SL}(\text{degrees})$	sweep angle of the wing at the leading edge of the wing
$\phi_{ST}(\text{degrees})$	sweep angle of the wing at the rear edge of the wing
$\phi_{s,s,T}(\text{degrees})$	sweep angle of the horizontal stabiliser at the rear edge of the horizontal stabiliser
$c_{t,s}(\text{ft})$	depth of the horizontal stabiliser outside
$c_{r,s}(\text{ft})$	depth of the horizontal stabiliser inside
$\phi_{s,s}(\text{degrees})$	sweep angle of the horizontal stabiliser in the centre of the horizontal stabiliser area
$\phi_{s,s,L}(\text{degrees})$	sweep angle of the horizontal stabiliser at the leading edge of the horizontal stabiliser
$F_{0,\text{per engine}}(\text{t})$	static jet thrust of an engine
$l(\text{ft})$	length of the aircraft's overall cargo compartment
$l_{\text{fuselage}}(\text{ft})$	length of the aircraft's overall fuselage
$l(\text{ft}) = l_{\text{Aeroplane}}$	length of the aircraft's overall cargo compartment
$h(\text{ft})$	height of the aircraft's overall cargo compartment
$b(\text{ft})$	width of the aircraft's overall cargo compartment
$b_s(\text{ft})$	wing span
$\bar{V}_{0,\text{nose CS}}(-)$	volume coefficient due to nose horizontal stabiliser
$\bar{V}_{0,\text{tail CS}}(-)$	volume coefficient due to tail horizontal stabiliser

Indices:

CS = control surfaces

Key

W_{Pay} (t)	max weight of payload
W_{max} (t)	max take-off weight
$\bar{V}_0$ (-)	volume coefficient of the horizontal stabiliser or that of the surfaces replacing the horizontal stabiliser
n_s	number of wings
Δl (ft)	distance of the centre of gravity of the aircraft to the reference line of the middle wing or the axis of symmetry of the wing system
c (ft)	depth of the wing at the point of the wing area's centre of gravity
b (ft)	width of the aircraft's overall cargo compartment
h (ft)	height of the aircraft's overall cargo compartment
l (ft)	length of the aircraft's overall cargo compartment
l_{fuselage} (ft)	length of the aircraft's fuselage
b_s (m)	wing span
Stabiliser	horizontal tail surfaces
Engine	power plant
Turboprop	turbojet engine with propeller

Key

C_L	Overall lift coefficient
$(dC_L/d\alpha)_s$	Lift increase of the wing
α_s (degrees)	Angle of attack of the wing
C_D	Overall drag coefficient
C_{D0}	Coefficient of the lift-independent drag
k	$1/\pi \cdot A_s$
A_s	Wing aspect ratio
$\Delta C_{L, \text{flap}}$	Variation of the overall lift coefficient caused by wing flap deflection
η (degrees)	Deflection angle of the wing flaps
l_1/l_2	Relation of the wing flap depth to the depth of the rigid part of the wing
$\Delta C_{D, \text{flap}}$	Variation of the overall drag coefficient caused by wing flap deflection
$(c_{\text{flap}}/b_{\text{flap}})$	Relation of the wing flap depth to the span of the wing flaps
S_{flap}/S	Relation of the wing flap area to the wing area
$C_{L, \text{flap}}$	Overall lift coefficient with wing flap deflection
$C_{D, \text{flap}}$	Overall drag coefficient with wing flap deflection
$\Delta\alpha_s$ (degrees)	Variation of the angle of attack of the wing part caused by wing flap deflection
C_D/C_L	Reciprocal lift/drag ratio of the aircraft

$(C_D/C_L)\gamma_{\min}$	Reciprocal lift/drag ratio of the aircraft with $\gamma_{\min}$
$(C_D/C_L)V_{Y, \min}$	Reciprocal lift/drag ratio of the aircraft with minimum rate of descent
$(C_D/C_L)R_{\max}$	Reciprocal lift/drag ratio of the aircraft for maximum range
(C_D/C_L)	Characteristic value of the reciprocal lift/drag ratio of the aircraft
(C_D^2/C_L^3)	Characteristic value of the reciprocal climb factor of the aircraft
(C_D^2/C_L)	Characteristic value of the reciprocal range factor of the aircraft
V_Y (ft/s)	Rate of descent of the aircraft
V (ft/s), (int miles/h)	Flight speed
W (lb), (t)	Weight of the aircraft
ρ (lb · s ² /ft ⁴)	Atmospheric density
S (ft ²), (m ²)	Reference wing area
P_e (level) (lb · ft/s)	Hover performance
F (lb), (t)	Useful thrust
(C_D/C_L)	Reciprocal lift/drag ratio of the aircraft
R (km), (int miles)	Range of the aircraft
$W_E/W_{\max}$	Relation of the operative weight empty to the take-off weight
$W_{\text{Pay}}/W_{\max}$	Relation of the payload weight to the take-off weight
$f \cdot F$ (lb/lb · h)	Specific fuel consumption of the engines

D/L	Reciprocal lift/drag ratio
D (lb), (t)	Flight drag
L (lb), (t)	Flight lift
q (lb/ft ²)	Dynamic pressure during flight
S _{flap, area} /S	Wing area portion of the flap zone compared to the reference wing area
$\Delta C_{Lmax, flap}$	Variation of the overall lift coefficient caused by maximum wing flap deflection
$\Delta \alpha_{max}$ (degrees)	Variation of the angle of attack of the wing part caused by maximum wing flap deflection
η_{max} (degrees)	Maximum wing flap deflection
$C_{Lmax, flap}$	Maximum overall lift coefficient with maximum wing flap deflection
$C_{Lmax, linear}$	Maximum overall lift coefficient without wing flap deflection in the linear zone
$\Delta C_{Dmax, flap}$	Variation of the overall drag coefficient caused by maximum wing flap deflection
γ_{min} (degrees)	Smallest gliding angle of the aircraft
C_{Lopt}	Overall lift coefficient with γ_{min}
$\eta_{flap} = \eta$ (degrees)	Deflection angle of the wing flap
η_{wing} (degrees)	Wing's rigging angle of incidence against the longitudinal axis of the fuselage

$(C_D/C_L)_{\min}$	Characteristic value of the smallest reciprocal lift/drag ratio
$(C_D^2/C_L^3)_{\min}$	Characteristic value of the smallest reciprocal climb factor
$(C_D^2/C_L)_{\min}$	Characteristic value of the smallest reciprocal range factor

Remark:

The symbols without dimensional information are without dimensions.

Key

Jet-engine	Engine
PPE	Propeller piston engine
PTJ	Propeller turbojet engine
TF	Bypass turbojet engine
TJ	Turbojet engine
F (lb); (t)	Power
m (lb · s ² /ft)	Mass
a (ft/s ²)	Acceleration
dV/dt (ft/s ²)	Speed change/time
dm/dt (lb · s/ft)	Mass change/time
t (s)	Time
V (ft/s); (int miles/h)	Speed, flight speed
V' (ft/s ²)	$= dV/dt$
m' (lb · s/ft)	$= dm/dt$
F (lb); (t)	Engine thrust
$m' \cdot V$ (lb); (t)	Impulse per second
$m'_J \cdot V_J$ (lb); (t)	Impulse per second at the engine outlet
$m'_I \cdot V_I$ (lb); (t)	Impulse per second at the engine inlet
V_J (ft/s)	Speed of the airflow at the engine outlet
V_I (ft/s)	Speed of the airflow at the engine inlet
m'_J (lb · s/ft)	Air quantity per second at the engine outlet
m'_I (lb · s/ft)	Air quantity per second at the engine inlet
$m \cdot V$ (lb · s); (t · s)	Impulse, stroke, thrust blast

F_1 (lb); (t)	Thrust generated by engine's main airflow
F_2 (lb); (t)	Thrust generated by engine's bypass airflow
$\dot{m}_1$ (lb · s/ft)	Air quantity of the engine's main airflow per second
$\dot{m}_2$ (lb · s/ft)	Air quantity of the engine's bypass airflow per second
V_1 (ft/s) = $(A_2/A_1) \cdot V_2$	Speed difference of the main airflow of the engine
V_2 (ft/s) = V/k	Speed difference of the bypass airflow of the engine
$k = V/V_2$	Factor, by which V is greater than V_2
ρ (lb · s ² /ft ⁴)	Atmospheric density
A_I (ft ²)	Cross-sectional area of the engine's overall airflow inlet
A_1 (ft ²)	Cross-sectional area of the engine's main airflow inlet
A_2 (ft ²)	Cross-sectional area of the engine's bypass airflow inlet
$F_{(level)}$ (lb); (t)	Thrust required for horizontal flight
$\varepsilon = C_D/C_L$	Reciprocal lift/drag ratio of the aircraft
C_D	Overall drag coefficient
C_L	Overall lift coefficient
W (lb); (t)	Weight of aircraft
d_I (ft)	Mean diameter of the engine's overall airflow inlet
l/d_I	Ratio of the engine's overall length/overall inlet diameter
A_2/A_1	By-pass ratio of the engine
A_1/A_I	Main-pass ratio of the engine

F_1 (lb); (t)	Thrust generated by engine's main airflow
F_2 (lb); (t)	Thrust generated by engine's bypass airflow
$\dot{m}_1$ (lb · s/ft)	Air quantity of the engine's main airflow per second
$\dot{m}_2$ (lb · s/ft)	Air quantity of the engine's bypass airflow per second
V_1 (ft/s) = $(A_2/A_1) \cdot V_2$	Speed difference of the main airflow of the engine Speed difference of the main airflow of the turbojet basic engine
V_2 (ft/s) = V/k	Speed difference of the bypass airflow of the engine Speed difference of the main airflow of the modified engine
$k = V/V_2$	Factor, by which V is greater than V_2
ρ (lb · s ² /ft ⁴)	Atmospheric density
A_1 (ft ²)	Cross-sectional area of the engine's overall airflow inlet
A_I (ft ²)	Cross-sectional area of the engine's main airflow inlet
A_2 (ft ²)	Cross-sectional area of the engine's bypass airflow inlet
$F_{(level)}$ (lb); (t)	Thrust required for horizontal flight
$\varepsilon = C_D/C_L$	Reciprocal lift/drag ratio of the aircraft
C_D	Overall drag coefficient
C_L	Overall lift coefficient
W (lb); (t)	Weight of aircraft
d_I (ft)	Mean diameter of the engine's overall airflow inlet
l/d_I	Ratio of the engine's overall length/overall inlet diameter
A_2/A_1	By-pass ratio of the engine
A_I/A_I	Main-pass ratio of the engine

$\Delta (l/d_I)_{\text{Turbojet}}$	$= (l/d_I)_{\text{Turbojet}} - (l/d_I)_{\text{Turboprop}}$
$(l/d_I)_{\text{Turbojet}}$	Ratio of overall length/overall inlet diameter of turbojet engine
$(l/d_I)_{\text{Turbofan}}$	Ratio of overall length/overall inlet diameter of turbofan engine
$(l/d_I)_{\text{Turboprop}}$	Ratio of overall length/overall diameter of turboprop engine
$(l/d_I)_{\text{Prop. Piston-engine}}$	Ratio of overall length/overall diameter of propeller piston engine
l_{Turbofan} (ft)	Overall length of the turbofan engine
ΔV (ft/s)	$= V_J - V_I$
l (ft)	Mean acceleration length of the engine
l_{Engine} (ft)	Theoretical length of the engine
p_I (lb/ft ²)	Static pressure of the airflow at the engine inlet
p_J (lb/ft ²)	Static pressure of the airflow at the engine outlet
p (lb/ft ²)	$1/3 \cdot (p_I - p_J)$
ρ_{average} (lb · s ² /ft ⁴)	Mean density of the airflow in the engine
$l_{\text{Engine, average}}$ (ft)	Mean theoretical length of the engine
$l_{\text{Engine 1}}$ (ft)	Theoretical length of the basic engine
a_1 (ft/s ²)	Mean acceleration in the basic engine
$l_{\text{Engine 2}}$ (ft)	Theoretical length of the modified engine
a_2 (ft/s ²)	Mean acceleration in the modified engine
A_{I1} (ft ²)	Cross-sectional area of the overall airflow inlet of the basic engine
d_{I1} (ft)	Mean diameter of the overall airflow inlet of the basic engine

A_{I2} (ft ²)	Cross-sectional area of the overall airflow inlet of the modified engine
d_{I2} (ft)	Mean diameter of the overall airflow inlet of the modified engine
A_1/A_I	Main-pass ratio
A_2/A_1	By-pass ratio
$l_{\text{Turboprop}}$ (ft)	Overall length of the turboprop engine
$l_{\text{Prop. Piston-engine}}$ (ft)	Overall length of the propeller piston engine

Indices:

I = Inlet

J = Jet

Remark:

The symbols without dimensional information are without dimensions.

Symbols

l_1	ground run distance for take-off
V_{TO}	velocity at take-off
b	mean acceleration during ground run to take-off
F	mean accelerating force during ground run to take-off
m	mass of the aeroplane at start
W	weight of the aeroplane at start
g	acceleration due to gravity
ρ	air density
S	reference wing area
$C_{L, TO}$	lift coefficient at take-off
(F/W)	reciprocal force load
(W/S)	wing area load

Designations

C_D	Total drag coefficient
C_{D0}	Coefficient of the drag independent of lift
A_S	Aspect ratio of the wing
C_L	Total lift coefficient
δ	Correction factor for the wing contour with induced drag
b (ft)	Wingspan width
S (ft ²)	Wing area
η	Profile degree of efficiency
c_{ts}/c_{rs}	Taper of the trapezoidal wing
α (arc)	Geometric angle of incidence of the wing
α_0 (arc)	Geometric angle of incidence of the wing with $A_S = \infty$
τ	Correction factor for the wing contour with induced angle of incidence
A_{S1}	Aspect ratio of the rear wing
C_{Di}	Coefficient of the induced drag
α_i (arc)	Induced angle of incidence
C_{Di1}	Coefficient of the induced drag of the rear wing
C_{Di2}	Coefficient of the induced drag of the front wing
C_{L1}	Lift coefficient of the rear wing
A_{S2}	Aspect ratio of the front wing
C_{L2}	Lift coefficient of the front wing
S_1 (ft ²)	Area of the rear wing
S_2 (ft ²)	Area of the front wing
α_{i1} (arc)	Induced angle of incidence of the rear wing
α_{i2} (arc)	Induced angle of incidence of the front wing

$C_{D,P1}$	Total drag coefficient for configuration principle 1
$C_{D0,P1}$	Coefficient of the drag independent of lift for configuration principle 1
k_{P1}	$(1/\pi \cdot A_S)_{P1}$
δ_{P1}	Correction factor for the wing contour with induced drag for configuration principle 1
α_{P1} (arc)	Geometric angle of incidence of the wing for configuration principle 1
$\alpha_{0,P1}$ (arc)	Geometric angle of incidence of the wing with $A_S = \infty$ for configuration principle 1
τ_{P1}	Correction factor for the wing contour with induced angle of incidence for configuration principle 1
$C_{D,P2}$	Total drag coefficient for configuration principle 2
$C_{D0,P2}$	Coefficient of the drag independent of lift for configuration principle 2
k_{P2}	$(1/\pi \cdot A_S)_{P2}$
δ_{P2}	Correction factor for the wing contour with induced drag for configuration principle 2
α_{P2} (arc)	Geometric angle of incidence of the wing for configuration principle 2
$\alpha_{0,P2}$ (arc)	Geometric angle of incidence of the wing with $A_S = \infty$ for configuration principle 2
τ_{P2}	Correction factor for the wing contour with induced angle of incidence for configuration principle 2
$C_{D,P4}$	Total drag coefficient for configuration principle 4
$C_{D0,P4}$	Coefficient of the drag independent of lift for configuration principle 4
k_{P4}	$(1/\pi \cdot A_S)_{P4}$
δ_{P4}	Correction factor for the wing contour with induced drag for configuration principle 4
α_{P4} (arc)	Geometric angle of incidence of the wing for configuration principle 4
$\alpha_{0,P4}$ (arc)	Geometric angle of incidence of the wing with $A_S = \infty$ for configuration principle 4
τ_{P4}	Correction factor for the wing contour with induced angle of incidence for configuration principle 4

$C_{D, P5}$	Total drag coefficient for configuration principle 5
$C_{D0, P5}$	Coefficient of the drag independent of lift for configuration principle 5
k_{P5}	$(1/\pi \cdot A_S)_{P5}$
δ_{P5}	Correction factor for the wing contour with induced drag for configuration principle 5
$\alpha_{P5} \text{ (arc)}$	Geometric angle of incidence of the wing for configuration principle 5
$\alpha_{0, P5} \text{ (arc)}$	Geometric angle of incidence of the wing with $A_S = \infty$ for configuration principle 5
τ_{P5}	Correction factor for the wing contour with induced angle of incidence for configuration principle 5
$C_{D0 \text{ fuselage, P1}}$	Coefficient of the drag independent of lift of the fuselage with control unit for configuration principle 1
$C_{D0 \text{ wing, P1}}$	Coefficient of the drag of the wing independent of lift with engine gondola for configuration principle 1
$C_{D \text{ profile, P1}}$	Coefficient of the profile drag of the wing for configuration principle 1
$C_{D \text{ interference, P1}}$	Coefficient of the interference drag of the wing with engine drag for configuration principle 1
$\Delta C_{D \text{ interference, P2}}$	Increase in the coefficient of the drag independent of lift for configuration principle 1 due to influencing of the wing with the front elevator unit
$\Delta C_{D \text{ profile, P1}}$	Increase in the coefficient of the profile drag for configuration principle 1 due to influencing of the wing with the front elevator unit
$\Delta S \text{ (ft}^2\text{)}$	Surface area of the wing area influenced by front elevator unit
$\Delta C_{D \text{ rear elevator}}$	Decrease the coefficient of the drag independent of lift for configuration principle 1 by omitting the rear elevator unit
$S_{\text{rear elevator}} \text{ (ft}^2\text{)}$	Elevator unit area
C_{D01}	Resistance coefficient in relation to maximum cross-sectional area
C_{D02}	Resistance coefficient in relation to the wing area

k	$(1/\pi \cdot A_S)$
R_{Tmax} (stat miles)	Range with maximum flying time
R_{max} (stat miles)	Maximum range
(W_{max}/D)	Lift/drag ratio of the aircraft
(C_L/C_D)	Lift/drag ratio of the aircraft
V (mph)	Flight speed
(C_D/C_L)	Reciprocal lift/drag ratio of the aircraft
$V/(C_D/C_L)$ (mph)	Quotient for the range calculation
(C_L/C_D^2)	Range number of the aircraft
$(C_D/C_L)_{Tmax}$	Reciprocal lift/drag ratio for maximum flying time of the aircraft
$(C_D/C_L)_{Rmax}$	Reciprocal lift/drag ratio for maximum range of the aircraft
$(V/(C_D/C_L))_{Tmax}$ (mph)	Quotient for the range calculation with maximum flying time
$(V/(C_D/C_L))_{Rmax}$ (mph)	Quotient for the range calculation with maximum range
k_R (lb · h/lb)	Factor of the range calculation
$C_{D0, Pi}$	Coefficient of the drag independent of lift of the various configuration principles
k_{Pi}	$(1/\pi \cdot A_S)$ of the various configuration principles
T_{max} (h)	Maximum flying time
k_{Tmax}	Factor of the lines of longest flying time
k_{Rmax}	Factor of the lines of greatest range
$(l_{fuselage}/d_{fuselage})$	Fuselage body aspect ratio
$C_{D0, fuselage\ body}$	Coefficient of the drag independent of lift of the fuselage body
$C_{D0, plate}$	Coefficient of the drag of a circular plate which is flown past $\perp$ to the plate level
$C_{D0, sphere}$	Coefficient of the drag of a sphere
$C_{D0, rod}$	Coefficient of the drag of a rod with $l_{fuselage} = \infty$ and $d_{fuselage} \rightarrow 0$

C_{D0} , fuselage body, P1	Coefficient of the drag independent of lift of the fuselage body for configuration principle 1
C_{D0} , engine gondola, P1	Coefficient of the drag independent of lift of the engine gondola for configuration principle 1
$C_{D \text{ profile}}$	$f(C_L)$, profile drag
$C_{D \text{ profile, P1}}$	Medium profile drag of the wing for configuration principle 1
$(l_{\text{engine gondola}}/d_{\text{engine gondola}})$	Engine gondola aspect ratio
VCS	Rudder unit
RHCS	Rear elevator unit
FHCS	Front elevator unit
S	Wing

Designations:

$R_{Tmax, Ferry}$ (stat miles)	ferry range, based on maximum flight time
$k_{R, Ferry}$ (lb · h/lb)	factor of the range calculation for ferry range
$(V/(C_D/C_L))_{Tmax, Ferry}$ (ft/s)	quotient for the range calculation, based on maximum flight time for ferry range
$R_{max, Ferry}$ (stat miles)	maximum ferry range
$(V/(C_D/C_L))_{Rmax, Ferry}$ (ft/s)	quotient for the range calculation, based on maximum range for ferry range
W_{Ferry} (lb); (t)	aircraft weight, flying weight for ferry range
R_{Ferry} (stat miles)	= $R_{max, Ferry}$
$R_{less reserves, Ferry}$ (stat miles)	maximum ferry range, minus the reserves
$R_{Tmax, less reserves, Ferry}$ (stat miles)	ferry range based on maximum flight time, minus the reserves
$W_{Pay, Ferry}$ (lb); (t)	weight of the payload in the aircraft for ferry range
$W_{Fuel max, theor.}$ (lb); (t)	theoretical maximum fuel
$W_{Fuel max}$ (lb); (t)	maximum fuel
$(V/(C_D/C_L))_{Rmax, 1}$ (ft/s)	quotient for calculating the range for maximum range with W_1
$(C_D/C_L)_{Rmax}$	reciprocal lift/drag ratio of the aircraft for R_{max}
$(V/(C_D/C_L))_{Rmax, 2}$ (ft/s)	quotient for calculating the range for maximum range with W_2
V_1 (ft/s); (mph)	flight speed for R_{max} with W_1
V_2 (ft/s); (mph)	flight speed for R_{max} with W_2
W_1 (lb); (t)	= W_{max}
$C_{L, Rmax}$	lift coefficient for R_{max}
W_2 (lb); (t)	reduced flying weight
$R_{Ferry, debit}$ (stat miles)	maximum ferry range without/with payload, without reserves, as stated by the manufacturer
$R_{less reserves, Ferry, debit}$ (stat miles)	maximum ferry range without/with payload, minus the reserves, as stated by the manufacturer

Designations:

R _w average, Ferry (stat miles)	maximum ferry range without/with payload, without reserves, based on average flying weight
R _w average, less reserves, Ferry (stat miles)	maximum ferry range without/with payload, minus the reserves, based on average flying weight
R _w average, less reserves, Ferry, debit (stat miles)	maximum ferry range without/with payload, minus the reserves, based on average flying weight, as stated by the manufacturer

Designations:

R_{Tmax} (stat miles)	range, based on maximum flight time
k_R (lb · h/lb)	factor of the range calculation
$(V/(C_D/C_L))_{Tmax}$ (ft/s)	quotient for the range calculation, based on maximum flight time
R_{max} (stat miles)	maximum range
$(V/(C_D/C_L))_{Rmax}$ (ft/s)	quotient for the range calculation, based on maximum range
R (stat miles)	= R_{max}
$R_{less\ reserves}$ (stat miles)	maximum range, minus the reserves
ΔR (stat miles)	distance between the destination airport and the alternate airport
R_{hold} (stat miles)	range, based on hold flight time
A_I (ft ²)	cross-sectional area of the engine's overall airflow inlet
C_D/C_L	reciprocal lift/drag ratio of the aircraft
W (lb); (t)	weight of the aircraft, flying weight
ρ (lb · s ² /ft ⁴)	atmospheric density
V (ft/s); (mph)	flight speed
$(C_D/C_L)_{opt}$	optimum reciprocal lift/drag ratio of the aircraft
C_{D0}	coefficient of the drag which is independent of the lift

Designations:

k	$(1/\pi \cdot A_s)$
V_{opt} (ft/s); (mph)	optimum flight speed
S (ft ²)	wing area
$n_{Engines}$	number of engines generating thrust
V_2 (ft/s)	speed difference ($V_J - V_I$) of the engine airflow with a given throttle position
V_1 (ft/s)	speed difference ($V_J - V_I$) of the engine airflow with a medium throttle position
V_J (ft/s)	speed of the airflow at the engine outlet
V_I (ft/s)	speed of the airflow at the engine inlet
A_{I2} (ft ²)	$(A_{I2}/A_{I1}) \cdot A_{I1}$
A_{I1} (ft ²)	cross-sectional area of the engine's overall airflow inlet, based on a basic engine
W_{Fuel} (lb); (t)	fuel weight
W_{max} (lb); (t)	maximum take-off weight of the aircraft
$f \cdot F$ (lb/lb · h)	specific fuel consumption of the engines
T (h)	flight time given, until all the fuel has been burned up
T_{hold} (min); (h)	flight time for the hold phase
$(W_{Fuel}/W_{max})_{hold}$	ratio of fuel weight / maximum take-off weight for the hold phase

Designations:

$F_{\text{(level)}} \text{ (lb); (t)}$	thrust of the engines for horizontal flight
$F \text{ (lb); (t); (lb st)}$	random thrust of the engines
$W_{\text{Pay}} \text{ (lb); (t)}$	weight of the payload in the aircraft
$W_E \text{ (lb); (t)}$	operation empty weight of the aircraft
$\text{Max } W_{\text{Pay}} \text{ (t)}$	maximum payload in the aircraft
$h \text{ (ft)}$	flight altitude
$W_{\text{Dry}} \text{ (lb)}$	dry weight of an engine
By-pass ratio	$= A_{12}/A_{11}$ of an engine
specific fuel consumption (lb/lb/hr)	$= V_{\text{spec}}$
$l_{\text{Engine}} \text{ (ft); (in)}$	overall length of the engine
$d \text{ (ft); (in)}$	$= d_i$
$d_i \text{ (ft); (in)}$	mean diameter of the engine's overall airflow inlet
$b \text{ (ft)}$	wing span
A_s	wing aspect ratio
$R_{\text{debit}} \text{ (stat miles)}$	maximum range with maximum payload, as stated by the manufacturer
$k_{R, \text{Ferry}} \text{ (lb} \cdot \text{h/lb)}$	factor of the range calculation for maximum range without payload, without reserves (for ferry range)

Designations:

R_{Ferry} (stat miles)	maximum range without payload, without reserves (ferry range)
$R_{\text{Ferry, debit}}$ (stat miles)	maximum range without payload, without reserves, as stated by the manufacturer
$R_{\text{less reserves, debit}}$ (stat miles)	maximum range with maximum payload, minus the reserves, as stated by the manufacturer
W_{average} (lb); (t)	average flying weight
$R_{W \text{ average}}$ (stat miles)	maximum range with maximum payload, without reserves, based on average flying weight
$R_{W \text{ average, debit}}$ (stat miles)	maximum range with maximum payload, without reserves, based on average flying weight, as stated by the manufacturer
$R_{T \text{ max, less reserves}}$ (stat miles)	range based on maximum flight time, with maximum payload, minus the reserves
h_{opt} (ft)	flight altitude for maximum cruising speed
P (HP)	propulsion power
η_{Prop}	propeller efficiency
$SFC_{\text{regarding } P}$ (lb/HP · h)	specific fuel consumption of the engines with propellers

Designations:

$h_0, \text{Aeroplane}^3 \text{ (ft}^3\text{)}$	Overall aircraft volume of the non-scaled aircraft
$h_0, \text{Aeroplane} \text{ (ft)}$	Height or width of the non-scaled overall aircraft's initial cargo compartment
$W_{\max} \text{ (t)}$	Maximum take-off weight of the non-scaled aircraft
$W_{\text{spec}} \text{ (t/ft}^3\text{)}$	Specific weight of the payload
$V_0, \text{Aeroplane, scale} \text{ (ft}^3\text{)}$	Overall aircraft volume of the scaled aircraft
$h_0, \text{Aeroplane, n} \text{ (ft)}$	Height or width of the scaled overall aircraft's initial cargo compartment
$W_{\max, \text{scale}} \text{ (t)}$	Maximum take-off weight of the scaled aircraft
n	Multiple of the maximum take-off weight of the non-scaled aircraft
k_{scale}	Scaling factor
$h_0, \text{Aeroplane, 2} \text{ (ft)}$	Height or width of the scaled overall aircraft's initial cargo compartment if $n = 2$
$h_0, \text{Aeroplane, 3} \text{ (ft)}$	Height or width of the scaled overall aircraft's initial cargo compartment if $n = 3$
$h_0, \text{Aeroplane, 4} \text{ (ft)}$	Height or width of the scaled overall aircraft's initial cargo compartment if $n = 4$
$h_0, \text{Aeroplane, 5} \text{ (ft)}$	Height or width of the scaled overall aircraft's initial cargo compartment if $n = 5$
$h_{\text{scale}}^3 \text{ (ft}^3\text{)}$	Volume of an aircraft cubicle of the scaled aircraft
$(W/S) \text{ (t/ft}^2\text{)}$	Wing load of the non-scaled aircraft
$S \text{ (ft}^2\text{)}$	Reference wing area of the non-scaled aircraft
$S_n \text{ (ft}^2\text{)}$	Reference wing area of the scaled aircraft
$(W/S)_n \text{ (t/ft}^2\text{)}$	Wing load of the scaled aircraft

Designations:

$W_E(t)$	Operational empty weight of the non-scaled aircraft
$W_{E1}(t)$	Operational empty weight of the scaled aircraft with scaling 1
$W_{\max,1}(t)$	Maximum take-off weight of the scaled aircraft with scaling 1
$W_{E2}(t)$	Operational empty weight of the scaled aircraft with scaling 2
$W_{\max,2}(t)$	Maximum take-off weight of the scaled aircraft with scaling 2
$W_{E3}(t)$	Operational empty weight of the scaled aircraft with scaling 3
$W_{\max,3}(t)$	Maximum take-off weight of the scaled aircraft with scaling 3
$W_{\text{Pay}}(t)$	Maximum payload weight of the non-scaled aircraft
$W_{\text{Pay},1}(t)$	Maximum payload weight of the scaled aircraft with scaling 1
$W_{\text{Pay},2}(t)$	Maximum payload weight of the scaled aircraft with scaling 2
$W_{\text{Pay},3}(t)$	Maximum payload weight of the scaled aircraft with scaling 3
$W_{\text{Fuel}}(t)$	Fuel weight of the non-scaled aircraft
$W_{\text{Fuel},1}(t)$	Fuel weight of the scaled aircraft with scaling 1
$W_{\text{Fuel},2}(t)$	Fuel weight of the scaled aircraft with scaling 2
$W_{\text{Fuel},3}(t)$	Fuel weight of the scaled aircraft with scaling 3
$(W/S)_{\text{scale}}(t/ft^2)$	Wing load of the generally scaled aircraft
$k_{\text{scale, geneal}}$	General scaling factor
n_{general}	Decimal number

Designations:

$\Delta C_{D0, \text{ fuselage body}}$	C_{w0} – change of the fuselage body due to extension or shortening of the fuselage
a	= 5.25
$(l_{\text{fuselage}}/d_{\text{fuselage}})_{a, b}$	Aspect ratio of the fuselage body of the extended or shortened aircraft fuselage
$(l_{\text{fuselage}}/d_{\text{fuselage}})$	Aspect ratio of the fuselage body without extension or shortening of the fuselage
$n_{\text{wheels, main gear}}$	Number of wheels of the main gear

Designations

R_{Tmax} (stat miles)	range, based on maximum flight time
k_R (lb · h/lb)	factor for the range calculation
$(V/(C_D/C_L))_{Tmax}$ (ft/s)	quotient for the range calculation, based on maximum flight time
R_{max} (stat miles)	maximum range
$(V/(C_D/C_L))_{Rmax}$ (ft/s)	quotient for the range calculation, based on maximum range
P/R	payload/range
W_E/W_{max}	empty weight quotient
W_{Pay}/W_{max}	payload quotient
SFC (lb/lb · h)	specific fuel consumption of the engines
W (lb); (t)	weight of the aircraft, flying weight
ρ (lb · s ² /ft ⁴)	atmospheric density
S (ft ²)	wing area
C_{D0}	drag coefficient independent of lift
k	$(1/\pi \cdot A_s)$
W_{max} (lb); (t)	maximum take-off weight of the aircraft
W_{Pay} (lb); (t)	weight of the payload in the aircraft
$W_{Fuel, max}$ (lb); (t)	weight of maximum fuel in aircraft
$W_{Pay, max}$ (lb); (t)	weight of maximum payload in aircraft
W_E (lb); (t)	Operational empty weight of aircraft
h (ft)	flight altitude

Designations

b)	symbol for short-range transport
$W_{\text{Fuel, b}} \text{ (lb); (t)}$	weight of fuel in aircraft for short-range transport
a)	symbol for medium-range transport
$W_{\text{Fuel, a}} \text{ (lb); (t)}$	weight of fuel in aircraft for medium-range transport
c)	symbol for long-range transport
$W_{\text{Fuel, c}} \text{ (lb); (t)}$	weight of fuel in aircraft for long-range transport
$R \text{ (stat miles)}$	$= R_{\text{max}}$
$(V/(C_D/C_L))_{T_{\text{max, h}}} \text{ (ft/s)}$	quotient for range calculation for maximum flight time as a function of flight altitude
k_h	$\sqrt{\rho/\rho_h}$
$(V/(C_D/C_L))_{R_{\text{max, h}}} \text{ (ft/s)}$	quotient for range calculation for maximum range as a function of flight altitude
$R_{T_{\text{max, h}}} \text{ (stat miles)}$	range for maximum flight time as a function of flight altitude
$R_{\text{max, h}} \text{ (stat miles)}$	maximum range as a function of flight altitude
$\rho_h \text{ (lb} \cdot \text{s}^2/\text{ft}^4\text{)}$	atmospheric density at flight altitude h
KONFPRINZ1A	computer program for calculation of ranges of constructed or designed aircrafts
KONFPRINZ1B	computer program for calculation of special velocities of constructed or designed aircrafts
M	flight Mach number
V_2/V_1	velocity ratio of throttle position
$\Delta C_{D0, \text{ Wave drag}}$	Wave drag coefficient percentage of total coefficient of drag independent of lift
$C_{D0, \text{ without Wave drag}}$	coefficient of drag independent of lift without wave drag
$F_{\text{mean, 1 Engine}} \text{ (lb)}$	average thrust of one engine

Designations

A_I (ft ²)	cross-sectional area of total engine airflow inlet
V (ft/s)	flight velocity
$F_{\max, 1 \text{ Engine}}$ (lb)	maximum thrust of one engine
$F_{\max, 2 \text{ Engines}}$ (lb)	maximum thrust of two engines
$(C_D/C_L)_{\text{opt}}$	reciprocal, optimum glide number of the aircraft
$R_{\text{less reserves}}$ (stat miles)	maximum range with maximum payload less reserves
R_{hold} (stat miles)	range due to hold flight time
$\rho_{7\text{km}}$ (lb · s ² /ft ⁴)	atmospheric density at 7 km flight altitude
γ (degrees)	angle of climb or glide
b (ft)	width of a hold element
h (ft)	height of a hold element
$b_{\text{Container}}$ (ft)	maximum width of the cargo container
CP_{general}	configuration principle general
$CP1$	configuration principle 1
$CP1.1$	scaled configuration principle 1.1
$CP1.2$	scaled configuration principle 1.2
$CP1.3$	scaled configuration principle 1.3
$CP1.6$	scaled configuration principle 1.6
b_{CP} (ft)	width of a hold element concerning a configuration principle

LIST OF SYMBOLS II (Addenda)

used only in the PhD Thesis

<u>Study Work Phase 1</u>	
C_D/C_L	reciprocal lift/drag ratio
$R_{\max}$ (km); (stat miles)	maximum range
<u>Study Work Phase 2</u>	
b (m); (ft)	width of the cargo compartment
$W_{\text{spec, aeroplane}}$ (t/m ³); (t/ft ³)	specific gravity of the aircraft
b_s (m); (ft)	wing span
$b_{\text{aeroplane}}$ (m); (ft)	width of the aircraft's overall cargo compartment
l_{fuselage} (m); (ft)	length of the aircraft's overall fuselage
M	scale
<u>Study Work Phase 3</u>	
$(W_{\max}/S)_{\text{aeroplane}}$ (t/m ²); (t/ft ²)	wing load of the aircraft
b_s (m); (ft)	horizontal stabiliser span
λ_s	taper ratio or span-chord ratio of the horizontal stabiliser
$l_{\text{aeroplane}}$ (m); (ft)	length of the aircraft's overall cargo compartment
$h_{\text{aeroplane}}$ (m); (ft)	height of the aircraft's overall cargo compartment
$b_{\text{aeroplane}}$ (m); (ft)	width of the aircraft's overall cargo compartment
l_{engine} (m); (ft); (in)	overall length of the engine
$(l/d_i)_{\text{engine}}$	overall length of the engine / mean diameter of the engine's overall airflow inlet
$d_{i, \text{engine}}$ (m); (ft); (in)	mean diameter of the engine's overall airflow inlet
S_i (m ²); (ft ²)	cross-sectional area of the engine's overall airflow inlet
(C_D/C_L)	reciprocal lift/drag ratio
$l_{s, s}$ (m); (ft)	moment arm of the horizontal stabiliser
M	scale

<u>Study Work Phase 4</u>	
M $b_{\text{aeroplane}}, h_{\text{aeroplane}}, l_{\text{aeroplane}}, W_{\text{max}}$	scale see Study Work Phase 3
<u>Study Work Phase 5</u>	-
<u>Study Work Phase 6</u>	
$C_{D0, \text{aeroplane}}$	coefficient of the aircraft's lift-independent drag
$k_{\text{aeroplane}}$	$1/(\pi \cdot A_S)$ of the aircraft
$(dC_L/d\alpha)_S, \text{aeroplane}$	lift increase of the aircraft's wing
$\Delta C_{L, \text{flap, aeroplane}}$	variation of the aircraft's overall lift coefficient caused by wing flap deflection
$\Delta C_{D, \text{flap, aeroplane}}$	variation of the aircraft's overall drag coefficient caused by wing flap deflection
$\alpha_{\text{max, linear}}$ (degrees)	maximum angle of attack without wing flap deflection in the linear zone
l_1 (m); (ft)	depth of the rigid part of the wing
l_2 (m); (ft)	wing flap depth
$\Delta\alpha$ (degrees) $h = l \cdot \sin \Delta\alpha$; $l = l_1 + l_2$	variation of angle of attack caused by wing flap deflection
<u>Study Work Phase 7</u>	
A_{I2}/A_{I1}	cross-sectional area of the overall airflow inlet of the modified engine / cross-sectional area of the overall airflow inlet of the basic engine
a_2/a_1	mean acceleration of the modified engine / mean acceleration of the basic engine
$(A_1/A_I)_{\text{Turbofan}}$	main-pass ratio of the Turbofan engine
d_I (m); (ft)	mean diameter of the engine's overall airflow inlet
W_{max} (t); (lb)	maximum take-off weight of the aircraft
V_{opt} (m/s); (ft/s)	flight speed with $C_{L, \text{opt}}$ on the wing
l_2/l_1	length of modified engine / length of basic engine
l_2 (m); (ft)	length of modified engine
l_1 (m); (ft)	length of basic engine

d_{12}/d_{11}	mean diameter of the overall airflow inlet of the modified engine / mean diameter of the overall airflow inlet of the basic engine
$(A_1/A_I)_{\text{Turbojet}}$	main-pass ratio of the turbojet engine
$(A_1/A_I)_{\text{Turboprop}}$	main-pass ratio of the turboprop engine
$(A_1/A_I)_{\text{Prop piston engine}}$	main-pass ratio of the propeller piston engine
$A_1 \text{ (m}^2\text{); (ft}^2\text{)}$	cross-sectional area of the engine's main airflow inlet
$A_2 \text{ (m}^2\text{); (ft}^2\text{)}$	cross-sectional area of the engine's bypass airflow inlet
$d_{I, \text{Turbojet}} \text{ (m); (ft)}$	mean diameter of the engine's overall airflow inlet with the turbojet engine
$d_{I, \text{Turbofan}} \text{ (m); (ft)}$	mean diameter of the engine's overall airflow inlet with the turbofan engine
$d_{I, \text{Turboprop}} \text{ (m); (ft)}$	mean diameter of the engine's overall airflow inlet with the turboprop engine
$d_{I, \text{Prop piston engine}} \text{ (m); (ft)}$	mean diameter of the engine's overall airflow inlet with the propeller piston engine
$l_{\text{Turbojet}} \text{ (m); (ft)}$	theoretical length of the turbojet engine
$l_{\text{Turbofan}} \text{ (m); (ft)}$	theoretical length of the turbofan engine
$l_{\text{Turboprop}} \text{ (m); (ft)}$	theoretical length of the turboprop engine
$l_{\text{Prop piston engine}} \text{ (m); (ft)}$	theoretical length of the propeller piston engine
$(l/d)_{\text{Turboprop}}$	ratio overall length / overall inlet diameter of the turboprop engine
$(l/d)_{\text{Prop piston engine}}$	ratio overall length / overall inlet diameter of the propeller piston engine
$b_s \text{ (m); (ft)}$	wing span
$b_{\text{aeroplane}} \text{ (m); (ft)}$	width of the aircraft's overall cargo compartment
$h_{\text{aeroplane}} \text{ (m); (ft)}$	height of the aircraft's overall cargo compartment
$l_{\text{aeroplane}} \text{ (m); (ft)}$	length of the aircraft's overall cargo compartment
$l_{\text{fuselage}} \text{ (m); (ft)}$	length of the aircraft's overall fuselage
<u>Study Work Phase 9</u>	
C_{D0}	coefficient of the lift-independent drag
C_{Di}	coefficient of the induced drag

$\Delta C_{D0, \text{landing gear}}$	variation of the aircraft's lift-independent drag coefficient caused by landing gear outside
$\Delta C_{D0, \text{engine}}$	variation of the aircraft's lift-independent drag coefficient caused by the engine
$(W/S)_{\max} \text{ (t/m}^2\text{); (t/ft}^2\text{)}$	maximum wing load
$W_{\max} \text{ (t)}$	maximum take-off weight of the aircraft
<u>Study Work Phase 8</u>	
$\Delta C_{L, \text{flap}}$	variation of the overall lift coefficient caused by wing flap deflection
$\Delta C_{D, \text{flap}}$	variation of the overall drag coefficient caused by wing flap deflection
$(dC_L/d\alpha)_s$	lift increase of the wing
$\eta \text{ (degrees)}$	deflection of the wing flaps
$l_1 \text{ (m); (ft)}$	depth of the rigid part of the wing
$l_2 \text{ (m); (ft)}$	wing flap depth
$S_{\text{flap area}} \text{ (m}^2\text{); (ft}^2\text{)}$	wing area of the flap zone
$(l/b)_{\text{flap}}$	relation of the wing flap depth to the span of the wing flaps
$S_{\text{flap}} \text{ (m}^2\text{); (ft}^2\text{)}$	wing flap area
$C_{D, \text{flap, P1}}$	overall drag coefficient with wing flap deflection with configuration principle 1
$\Delta C_{D, \text{flap, P1}}$	variation of the overall drag coefficient caused by wing flap deflection with configuration principle 1
$C_{L, \text{flap}}$	overall lift coefficient caused by wing flap deflection
$\Delta C_{L, \text{flap, P1}}$	variation of the overall lift coefficient caused by wing flap deflection with configuration principle 1
$W \text{ (t); (lb)}$	take-off weight of the aircraft
$\rho \text{ (kp} \cdot \text{s}^2/\text{m}^4\text{); (lb} \cdot \text{s}^2/\text{ft}^4\text{)}$	atmospheric density
a	factor = 5,25
$C_{D0, \text{engine gondola}}$	lift-independent drag of the engine gondola
$C_{D0, \text{wing}}$	lift-independent drag of the wing
$\Delta C_{D0, \text{landing gear}}$	variation of the aircraft's lift-independent drag coefficient caused by landing gear outside

$W_{\max}$ (t); (lb)	maximum take-off weight of the aircraft
W_{Pay} (t); (lb)	payload weight
h (km)	flying hight
$T_{\max}$ (h)	maximum flight time
<u>Study Work Phase 10 und 10a</u>	
R (km); (stat miles)	maximum range
ϵ	reciprocal lift/drag ratio of the aircraft
R_{Ferry} (km); (stat miles)	maximum range without payload, without reserves
n	number of engines
TJ	turbo jet engine
PTJ	turboprop jet engine
δ	correction factor for the wing contour with induced drag
C_{D0} , aeroplane, category i	lift-independent drag of the aircraft with category i
l (m); (ft)	total length of the engine
R_{Ferry} (km); (stat miles)	ferry range
h_{opt} (km); (ft)	flight altitude for maximum range
<u>Study Work Phase 11</u>	
$W_{\max}$ (t); (lb)	maximum take-off weight of the aircraft
$(W_{\max}/S)_{\text{scale}}$ (t/m ²); (t/ft ²)	maximum wing load of the generally scaled aircraft
$V_{0, \text{aeroplane}}$ (m ³); (ft ³)	overall aeroplane volume of the scaled aircraft non-
$V_{0, \text{aeroplane, scale, general}}$ (m ³); (ft ³)	overall aeroplane volume of the generally scaled aircraft
h_0 , aeroplane, general (m); (ft)	height of the cube of the overall aeroplane volume of the generally scaled aircraft
$(W_{\max}/S)_n$ (t/m ²); (t/ft ²)	maximum wing load of the scaled aircraft
$(W/S)_n$ (t/m ²); (t/ft ²)	wing load of the scaled aircraft

<u>Study Work Phase 12</u>	
$(1/\text{SFC}) \text{ (kp} \cdot \text{h/kg); (lbf} \cdot \text{hr/lb)}$	reciprocal value of the specific fuel consumption of the engine
$(V/\epsilon) \text{ (m/s); (ft/s)}$	flight speed / reciprocal glide number of the aircraft
$h \text{ (km); (ft)}$	flight altitude
flying hight	
$S_{I, \text{TO}} \text{ (km); (ft)}$	ground run distance for take-off
$S_{I, \text{LA}} \text{ (km); (ft)}$	ground run distance for landing

APPENDIX C

CRANFIELD UNIVERSITY

A. MEDERER

**THE DEVELOPMENT OF A DESIGN METHODOLOGY
FOR LARGE CARGO AIRCRAFT**

SCHOOL OF ENGINEERING

PhD THESIS

- Methodisches Entwerfen von Verkehrsflugzeugen

Institut für Flugzeugbau und Leichtbau
Technische Universität Carolo- Wilhelmina zu Braunschweig

- Konstruktionsmethodik und Flugzeugentwurf

Prof. Dipl. Ing. Erhard Rumpler
Fachhochschule München
Fachbereich Maschinenbau, Fahrzeugtechnik, Luftfahrttechnik

- Multidisziplinärer Flugzeugentwurf
mit dem Programmsystem PRADO-
Konzept und Anwendung

Dr. Ing. Wolfgang Heinze
Institut für Flugzeugbau und Leichtbau (IFL)
der TU Braunschweig

APPENDIX D

CRANFIELD UNIVERSITY

A. MEDERER

**THE DEVELOPMENT OF A DESIGN METHODOLOGY
FOR LARGE CARGO AIRCRAFT**

SCHOOL OF ENGINEERING

PhD THESIS

CRANFIELD UNIVERSITY

SCHOOL OF ENGINEERING

PhD THESIS

Academic Year 2007/2008

A. MEDERER

**The Development of a Design Methodology
For Large Cargo Aircraft**

Supervisor:

J. P. Fielding

November 2008

**This thesis is submitted in partial fulfilment of the requirements
for the degree of PhD**

Concerning study phase 1, page 1 and 2

Flying time and range:

$$\text{SFC} = W_{\text{Fuel}} / (F \cdot T)$$

$$F = W_{\text{max}} \cdot (C_D/C_L)$$

$$\text{SFC} = W_{\text{Fuel}} / (W_{\text{max}} \cdot (C_D/C_L) \cdot T)$$

$$W_{\text{Fuel}}/W_{\text{max}} = \text{SFC} \cdot (C_D/C_L) \cdot T \quad (3)$$

$$T = W_{\text{Fuel}} / (W_{\text{max}} \cdot \text{SFC} \cdot (C_D/C_L))$$

$$T = (W_{\text{Fuel}}/W_{\text{max}}) \cdot (1/\text{SFC}) \cdot (1/(C_D/C_L))$$

$$W_{\text{max}} = W_E + W_{\text{Pay}} + W_{\text{Fuel}} \quad (1)$$

$$W_{\text{Fuel}} = W_{\text{max}} - W_E - W_{\text{Pay}}$$

$$W_{\text{Fuel}}/W_{\text{max}} = 1 - W_E/W_{\text{max}} - W_{\text{Pay}}/W_{\text{max}}$$

$$T = (1 - W_E/W_{\text{max}} - W_{\text{Pay}}/W_{\text{max}}) \cdot (1/\text{SFC}) \cdot (1/(C_D/C_L)) \quad (5)$$

$$T = R / V$$

$$R = T \cdot V$$

$$R = (1 - W_E/W_{\text{max}} - W_{\text{Pay}}/W_{\text{max}}) \cdot (1/\text{SFC}) \cdot (1/(C_D/C_L)) \cdot V \quad (6)$$

$$T = (1 - (W_E/W_{\text{max}})_{\text{acroplane}} - (W_{\text{Pay}}/W_{\text{max}})_{\text{acroplane}}) \cdot (1/(\text{SFC})_{\text{acroplane}}) \cdot (1/(C_D/C_L)_{\text{acroplane}}) \quad (7)$$

$$R = (1 - (W_E/W_{\text{max}})_{\text{acroplane}} - (W_{\text{Pay}}/W_{\text{max}})_{\text{acroplane}}) \cdot (1/(\text{SFC})_{\text{acroplane}}) \cdot (1/(C_D/C_L)_{\text{acroplane}}) \cdot V \quad (8)$$

Concerning study phase 2, page 1 and 2

Overall aeroplane hold and cargo space:

$$V_0 = h_0^3$$

$$h_0 = 2 \cdot h$$

$$h_0^3 = (2 \cdot h)^3 = 8 \cdot h^3$$

$$h_0^3 = h^2 \cdot l = h^3 \cdot (l/h)$$

$$l/h = 1/(h/l)$$

$$h/l = k$$

$$h_0^3 = h^3 \cdot (1/k)$$

$$h_0^3 = h^2 \cdot l = h^3 \cdot (l/h) = h^3 \cdot (1/k) \quad (9)$$

$$h_0 = h \cdot (l/h)^{1/3} = h \cdot (1/k)^{1/3}$$

$$h = h_0 \cdot k^{1/3} = h_0 \cdot (h/l)^{1/3} \quad (14)$$

$$(h/l)^{1/3} = h/h_0$$

$$h/l = (h/h_0)^3$$

$$l/h = (h_0/h)^3$$

$$l = h \cdot (h_0/h)^3 = h_0^3/h^2 = h_0 \cdot (h_0/h)^2$$

$$(h_0/h)^2 = ((l/h)^{1/3})^2 = ((1/k)^{1/3})^2 = (1/k)^{2/3}$$

$$l = h_0 \cdot (1/k)^{2/3} = h_0 \cdot (1/(h/l)^{2/3}) \quad (16)$$

$$h/l = 1/8$$

$$h = 5 \quad h_{\text{aeroplane}}$$

$$h_0 = 2 \cdot h = 10$$

$$l = 10 \cdot (1/(1/8))^{2/3} = 40 \quad l_{\text{aeroplane}}$$

Wing and horizontal tail:

$$\begin{aligned}L_{\text{acroplane}} &= (\rho/2) \cdot V_{\min}^2 \cdot C_{L\max} \cdot S_{\text{acroplane}} \\L_{\text{acroplane}} &= W_{\max} \\W_{\max} &= (\rho/2) \cdot V_{\min}^2 \cdot C_{L\max} \cdot S_{\text{acroplane}} \\S_{\text{acroplane}} &= S \\(W_{\max}/S)_{\text{acroplane}} &= (\rho/2) \cdot V_{\min}^2 \cdot C_{L\max}\end{aligned}\tag{19}$$

$$\begin{aligned}A_S &= b_S^2 / S \\b_S &= (A_S \cdot S)^{1/2}\end{aligned}\tag{20}$$

$$\begin{aligned}k &= 1 / (\pi \cdot A_S) \\A_S &= 1 / (\pi \cdot k)\end{aligned}\tag{21}$$

$$\begin{aligned}\bar{V}_0 &= S_s \cdot l_{s,s} / (S \cdot c) \\S_s &= \bar{V}_0 \cdot (S \cdot c) / l_{s,s}\end{aligned}\tag{23}$$

$$\begin{aligned}S_s &= b_s \cdot (c_{ts} + c_{rs})/2 \\b_s &= S_s / ((c_{ts} + c_{rs})/2)\end{aligned}\tag{24}$$

$$\begin{aligned}C_D &= 2 \cdot C_{D0} = C_{D0} + k \cdot C_{L\text{opt}}^2 \\k \cdot C_{L\text{opt}}^2 &= C_{D0} \\C_{L\text{opt}} &= (C_{D0}/k)^{1/2}\end{aligned}\tag{26}$$

re. study phase 3, page 2

Fuselage and engine pod:

$$h_0 = 2 \cdot h_{\text{aeroplane}}$$

$$k = h_{\text{aeroplane}} / l_{\text{aeroplane}}$$

$$l_{\text{aeroplane}} = h_0 \cdot (1/k)^{2/3} \quad (16)$$

$$l_{\text{fuselage nose}} = 1.5 \cdot h_{\text{aeroplane}}$$

$$l_{\text{fuselage tail}} = 2.0 \cdot h_{\text{aeroplane}}$$

$$l_{\text{fuselage nose}} + l_{\text{fuselage tail}} = 1.5 \cdot h_{\text{aeroplane}} + 2.0 \cdot h_{\text{aeroplane}} = 3.5 \cdot h_{\text{aeroplane}} \quad (27)$$

$$l_{\text{fuselage}} = l_{\text{aeroplane}} + 3.5 \cdot h_{\text{aeroplane}}$$

$$l_{\text{engine}} = (l/d_I)_{\text{engine}} \cdot d_{I, \text{engine}} \quad (28)$$

$$S_I = (1/4) \cdot d_{I, \text{engine}}^2 \cdot \pi$$

$$d_{I, \text{engine}} = (4 \cdot S_I / \pi)^{1/2} \quad (29)$$

$$F = (C_D / C_L) \cdot W_{\text{max}}$$

$$F = S_I \cdot \rho \cdot V_{\text{opt}}^2$$

$$S_I \cdot \rho \cdot V_{\text{opt}}^2 = (C_D / C_L) \cdot W_{\text{max}}$$

$$S_I = (C_D / C_L) \cdot W_{\text{max}} / (\rho \cdot V_{\text{opt}}^2) \quad (30)$$

$$L_{\text{aeroplane}} = (\rho/2) \cdot V_{\text{opt}}^2 \cdot C_{L\text{opt}} \cdot S$$

$$L_{\text{aeroplane}} = W_{\text{max}}$$

$$W_{\text{max}} = (\rho/2) \cdot V_{\text{opt}}^2 \cdot C_{L\text{opt}} \cdot S$$

$$V_{\text{opt}}^2 = 2 \cdot W_{\text{max}} / (\rho \cdot C_{L\text{opt}} \cdot S)$$

re. study phase 6, page 1 and 2

Variable aircraft polar:

$$C_L = (dC_L/d\alpha)_S \cdot \alpha_S \quad (32)$$

$$\Delta\alpha_{\text{flap}} = \sin \eta / (l_1/l_2 + \cos \eta) \cdot S_{\text{flap, area}}/S$$

$$\Delta C_{L, \text{flap}} = (dC_L/d\alpha)_S \cdot \Delta\alpha_{\text{flap}}$$

$$\Delta C_{L, \text{flap}} = (dC_L/d\alpha)_S \cdot \sin \eta / (l_1/l_2 + \cos \eta) \cdot S_{\text{flap, area}}/S \quad (69)$$

$$C_{L, \text{flap}} = C_L + \Delta C_{L, \text{flap}} \quad (34)$$

$$C_D = C_{D0} + k \cdot C_L^2 \quad (31)$$

$$\Delta C_{D, \text{flap}} = 1,0 \cdot (l/b)_{\text{flap}} \cdot S_{\text{flap}}/S \cdot |\sin \eta| \quad (70)$$

$$C_{D, \text{flap}} = C_{D0} + \Delta C_{D, \text{flap}} + k \cdot (C_{L, \text{flap}} - \Delta C_{L, \text{flap}})^2 \quad (33)$$

$$C_{D, \text{flap}} = C_{D0} + \Delta C_{D, \text{flap}} + k \cdot (C_L + \Delta C_{L, \text{flap}} - \Delta C_{L, \text{flap}})^2$$

$$C_{D, \text{flap}} = C_{D0} + \Delta C_{D, \text{flap}} + k \cdot C_L^2$$

$(C_D/C_L)_{\min}$:

$$C_D/C_L = 2 \cdot C_{D0}/(C_{D0}/k)^{1/2}$$

$$C_D/C_L = (4 \cdot C_{D0}^2/C_{D0} \cdot k)^{1/2}$$

$$C_D/C_L = 2 \cdot (C_{D0} \cdot k)^{1/2} \quad 1.$$

$(C_D^2/C_L^3)_{\min}$:

$$C_D/C_L = 4 \cdot C_{D0}/(3 \cdot C_{D0}/k)^{1/2}$$

$$C_D/C_L = (16 \cdot C_{D0}^2/(3 \cdot C_{D0}) \cdot k)^{1/2}$$

$$C_D/C_L = (4/3)^{1/2} \cdot 2 \cdot (C_{D0} \cdot k)^{1/2} \quad 2.$$

$(C_D^2/C_L)_{\min}$:

$$C_D/C_L = (4/3) \cdot C_{D0}/(C_{D0}/(3 \cdot k))^{1/2}$$

$$C_D/C_L = (16/9 \cdot C_{D0}^2/C_{D0} \cdot 3 \cdot k)^{1/2}$$

$$C_D/C_L = (4/3)^{1/2} \cdot 2 \cdot (C_{D0} \cdot k)^{1/2} \quad 3.$$

re. study phase 7, page 3

Engine size:

$$(A_I/A_I)_{\text{Turbofan}} = 0 \text{ to } 1.0 \quad (44)$$

$$(A_I/A_I)_{\text{Turbojet}} = 1.0 \quad (45)$$

$$\Delta(l/d_I)_{\text{Turbojet}} = 0.8 \quad (43)$$

$$(l/d_I)_{\text{Prop piston engine}} = 1.0 \quad (42)$$

$$(l/d_I)_{\text{Turboprop}} = 2.1 \cdot (l/d_I)_{\text{Prop piston engine}} \quad (41)$$

$$(l/d_I)_{\text{Turbofan}} = (l/d_I)_{\text{Turboprop}} + (A_I/A_I)_{\text{Turbofan}} \cdot \Delta(l/d_I)_{\text{Turbojet}} \quad (40)$$

$$(l/d_I)_{\text{Turbofan}} = 2.1 \cdot (l/d_I)_{\text{Prop piston engine}} + (A_I/A_I)_{\text{Turbofan}} \cdot \Delta(l/d_I)_{\text{Turbojet}}$$

$$(l/d_I)_{\text{Turbojet}} = (l/d_I)_{\text{Turboprop}} + (A_I/A_I)_{\text{Turbojet}} \cdot \Delta(l/d_I)_{\text{Turbojet}}$$

$$(l/d_I)_{\text{Turbojet}} = 2.1 \cdot (l/d_I)_{\text{Prop piston engine}} + (A_I/A_I)_{\text{Turbojet}} \cdot \Delta(l/d_I)_{\text{Turbojet}}$$

$$(l/d_I)_{\text{Turbojet}} = (l/d_I)_{\text{Turboprop}} + \Delta(l/d_I)_{\text{Turbojet}} \quad (46)$$

$$(l/d_I)_{\text{Turbojet}} = 2.1 \cdot (l/d_I)_{\text{Prop piston engine}} + \Delta(l/d_I)_{\text{Turbojet}}$$

$$F_{(\text{level})} = (C_D/C_L) \cdot W_{\text{max}} \quad (49)$$

$$F_{(\text{level})} = A_I \cdot \rho \cdot V_{\text{opt}}^2$$

$$A_I \cdot \rho \cdot V_{\text{opt}}^2 = (C_D/C_L) \cdot W_{\text{max}}$$

$$A_I = (C_D/C_L) \cdot W_{\text{max}} / (\rho \cdot V_{\text{opt}}^2) \quad (48)$$

$$A_I = (1/4) \cdot d_I^2 \cdot \pi$$

$$d_I = (4 \cdot A_I / \pi)^{1/2} \quad (47)$$

$$l = (l/d_I) \cdot d_I \quad (50)$$

re. study phase 7, page 3

Engine parameter:

$$A_I = A_1 + A_2$$

$$A_I = A_1 - A_2$$

$$A_I/A_I = (A_I - A_2)/(A_1 + A_2)$$

$$A_I/A_I = (A_I - A_2)/(A_1 \cdot (1 + A_2/A_1))$$

$$A_I/A_I = (A_I - A_2)/A_1 / (1 + A_2/A_1)$$

$$A_I/A_I = 1/(1 + A_2/A_1) \quad (51)$$

$$A_2 = A_I - A_1$$

$$A_I \cdot V = A_1 \cdot V_1 + A_2 \cdot V_2$$

$$A_I = A_1 \cdot (V_1/V) + A_2 \cdot (V_2/V)$$

$$A_I = A_1 \cdot (V_1/V) + (A_I - A_1) \cdot (V_2/V)$$

$$A_I/A_I = (V_1/V) + ((A_I - A_1)/A_1) \cdot (V_2/V)$$

$$A_I/A_I = (V_1/V) + ((A_I/A_1) - 1) \cdot (V_2/V)$$

$$A_I/A_I = (V_1/V) + (A_I/A_1) \cdot (V_2/V) - (V_2/V)$$

$$A_I/A_I - (A_I/A_1) \cdot (V_2/V) = (V_1/V) - (V_2/V)$$

$$(A_I/A_1) \cdot (1 - (V_2/V)) = (V_1/V) - (V_2/V)$$

$$(A_I/A_1) = ((V_1/V) - (V_2/V))/(1 - (V_2/V))$$

$$(A_I/A_1) = (1 - (V_2/V))/((V_1/V) - (V_2/V))$$

$$(A_I/A_1) = (1 - (V_2/V))/((V_1/V_2) - 1) \cdot (V_2/V)$$

$$(A_I/A_1) = (V_2/V) \cdot ((V/V_2) - 1)/((V_1/V_2) - 1) \cdot (V_2/V)$$

$$(A_I/A_1) = ((V/V_2) - 1)/((V_1/V_2) - 1)$$

$$V/V_2 = k$$

$$V_1/V_2 = A_2/A_1$$

$$A_I/A_I = (k - 1)/(A_2/A_1 - 1) \quad (52)$$

re. study phase 7, page 3

Engine outer dimension ratios :

$$l_1 = V_1^2 / (2 \cdot a_1)$$

$$l_2 = V_2^2 / (2 \cdot a_2)$$

$$d_{11} = (4 \cdot A_{11} / \pi)^{1/2}$$

$$d_{12} = (4 \cdot A_{12} / \pi)^{1/2}$$

$$l_2 / l_1 = V_2^2 / (2 \cdot a_2) / (V_1^2 / (2 \cdot a_1))$$

$$l_2 / l_1 = (V_2 / V_1)^2 \cdot (a_1 / a_2) \quad (54)$$

$$d_{12} / d_{11} = (4 \cdot A_{12} / \pi)^{1/2} / (4 \cdot A_{11} / \pi)^{1/2}$$

$$d_{12} / d_{11} = (A_{12} / A_{11})^{1/2} \quad (55)$$

$$l_2 = (V_2 / V_1)^2 \cdot (a_1 / a_2) \cdot l_1$$

$$d_{12} = (A_{12} / A_{11})^{1/2} \cdot d_{11}$$

$$l_2 / d_{12} = (V_2 / V_1)^2 \cdot (a_1 / a_2) \cdot l_1 / ((A_{12} / A_{11})^{1/2} \cdot d_{11})$$

$$l_2 / d_{12} = (V_2 / V_1)^2 / (A_{12} / A_{11})^{1/2} \cdot (a_1 / a_2) \cdot (l_1 / d_{11}) \quad (56)$$

re. study phase 9, page 2

Runway length:

$$F/W = \text{constant} = 0.2 \quad \text{reciprocal force load} \quad (59)$$

$$b = F/m = F/(W/g) = (F/W) \cdot g \quad (58)$$

$C_{L,TO}$ = lift coefficient at take-off

$$W = L$$

$$L = C_{L,TO} \cdot \rho/2 \cdot V_{TO}^2 \cdot S$$

$$W = C_{L,TO} \cdot \rho/2 \cdot V_{TO}^2 \cdot S$$

$$W/S = C_{L,TO} \cdot \rho/2 \cdot V_{TO}^2 \quad \text{wing load of the aircraft}$$

$$V_{TO} = ((2/\rho) \cdot (W/S) \cdot (1/C_{L,TO}))^{1/2} \quad (60)$$

$$l_1 = V_{TO}^2/(2 \cdot b) \quad (57)$$

tudy phase 8, page 2

mation zero drag and induced drag:

figuration principle 1:

$$C_{D, \text{profile}, P1} = 0.006$$

$$C_{D, \text{interference}, P1} = 0.25 \cdot C_{D, \text{profile}, P1} = 0.0015$$

$$C_{D, \text{wing}, P1} = C_{D, \text{profile}, P1} + C_{D, \text{interference}, P1}$$

$$C_{D0, \text{fuselage}, P1} = C_{D0, \text{wing}, P1}$$

$$C_{D0, P1} = C_{D0, \text{fuselage}, P1} + C_{D0, \text{wing}, P1} = 2 \cdot C_{D0, \text{wing}, P1}$$

$$C_{D0, P1} = 2 \cdot (C_{D, \text{profile}, P1} + C_{D, \text{interference}, P1}) \quad (61)$$

$$C_{D0, P1} = 2 \cdot C_{D, \text{profile}, P1} \cdot (1 + 0.25) = 2 \cdot 1.25 \cdot C_{D, \text{profile}, P1}$$

$$C_{D0, P1} = 2.5 \cdot C_{D, \text{profile}, P1} = 2.5 \cdot 0.006 = \underline{0.015}$$

figuration principle 2:

$$C_{D0, P1} = 0.015$$

$$C_{D, \text{profile}, P1} = 0.004 \quad \text{profile roughness}$$

$$S = 0.5$$

$$C_{D, \text{interference}, P2} = \Delta C_{D, \text{profile}, P1} \cdot (\Delta S/S) = 0.004 \cdot 0.5 = 0.002 \quad (63)$$

$$C_{D0, P2} = C_{D0, P1} + \Delta C_{D, \text{interference}, P2} = 0.015 + 0.002 = \underline{0.017} \quad (62)$$

figuration principle 4:

$$C_{D0, P1} = 0.015$$

$$C_{D0, P1} = 2 \cdot C_{D0, \text{wing}, P1}$$

$$C_{D0, \text{wing}, P1} = 0.5 \cdot C_{D0, P1}$$

$$C_{D0, P4} = C_{D0, P1} + C_{D0, \text{wing}, P1}$$

$$C_{D0, P4} = C_{D0, P1} + 0.5 \cdot C_{D0, P1} = C_{D0, P1} \cdot (1 + 0.5) = 1.5 \cdot C_{D0, P1} \quad (64)$$

$$C_{D0, P4} = 1.5 \cdot 0.015 = \underline{0.0225}$$

udy phase 8, page 2

ation zero drag and induced drag:

guration principle 5:

$$C_{D0,P1} = 0.015$$

$$C_{D\text{ profile},P1} = 0.006$$

$$C_{D\text{ interference},P1} = 0.0015$$

$$C_{D\text{ rear elevator}} = (C_{D\text{ profile},P1} + (1/2) \cdot C_{D\text{ interference},P1}) \cdot (S_{\text{rear elevator}}/S)$$

(66)

$$C_{D\text{ rear elevator}} = (0.006 + 0.5 \cdot 0.0015) \cdot 0.3875 = 0.0026$$

$$C_{D0,P1} - \Delta C_{D\text{ rear elevator}} = 0.015 - 0.0026 = \underline{0.0124}$$

(65)

$$C_{D0,P1} = 1/(\pi \cdot A_S)$$

(67)

$$C_{D0,P1} = C_{D0,P1} + k_{P1} \cdot C_{L,P1}^2$$

(71)

$$C_{L,P1} = C_{L1,P1} + C_{L2,P1}$$

$$C_{L,P1} = C_{L1,P1} + C_{L2,P1}$$

$$C_{D0,P1} = C_{D0,P1} + k_{P1} \cdot C_{L1,P1}^2 + k_{P1} \cdot C_{L2,P1}^2$$

$$C_{D0,P1} = C_{D0,P1} + k_{P1} \cdot ((1/2) \cdot C_{L,P1})^2 + k_{P1} \cdot ((1/2) \cdot C_{L,P1})^2$$

$$C_{D0,P1} = C_{D0,P1} + 2 \cdot k_{P1} \cdot (1/4) \cdot C_{L,P1}^2 = C_{D0,P1} + (1/2) \cdot k_{P1} \cdot C_{L,P1}^2$$

$$C_{D0,P1} = C_{L,P1}$$

$$C_{D0,P1} = (1/2) \cdot k_{P1}$$

(68)

$$C_{D0,P1} = C_{D0,P1} + k_{P1} \cdot C_{L,P1}^2$$

(73)

re. study phase 8, page 3

Flying performance:

$$L = C_L \cdot (\rho/2) \cdot V^2 \cdot S$$

$$L = W$$

$$W = C_L \cdot (\rho/2) \cdot V^2 \cdot S$$

$$C_L = (C_{D0}/k)^{1/2} = C_{L, \text{opt}}$$

$$W = (C_{D0}/k)^{1/2} \cdot (\rho/2) \cdot V^2 \cdot S$$

$$V^2 = W/(C_{D0}/k)^{1/2} \cdot (2/\rho) \cdot (1/S)$$

$$V = (2 \cdot W/(\rho \cdot S)/(C_{D0}/k)^{1/2})^{1/2} = V_{Tmax}$$

$$\varepsilon = 2 \cdot (C_{D0} \cdot k)^{1/2} = \varepsilon_{Tmax} \quad 1.$$

$$V = (2 \cdot W/(\rho \cdot S))^{1/2}/(C_{D0}/k)^{1/4}$$

$$V/\varepsilon = (2 \cdot W/(\rho \cdot S))^{1/2}/((C_{D0}/k)^{1/4} \cdot 2 \cdot (C_{D0} \cdot k)^{1/2})$$

$$V/\varepsilon = (2 \cdot W/(\rho \cdot S))^{1/2}/((C_{D0}/k)^{1/4} \cdot 2 \cdot ((C_{D0} \cdot k)^2)^{1/4})$$

$$V/\varepsilon = (2 \cdot W/(\rho \cdot S))^{1/2}/(((C_{D0}/k) \cdot (C_{D0}^2 \cdot k^2))^{1/4} \cdot 2)$$

$$V/\varepsilon = (2 \cdot W/(\rho \cdot S))^{1/2}/(2 \cdot (C_{D0}^3 \cdot k)^{1/4}) = (V/\varepsilon)_{Tmax} \quad (78)$$

$$C_L = (C_{D0}/(3 \cdot k))^{1/2} = C_{L, Rmax}$$

$$W = (C_{D0}/(3 \cdot k))^{1/2} \cdot (\rho/2) \cdot V^2 \cdot S$$

$$V^2 = W/(C_{D0}/(3 \cdot k))^{1/2} \cdot (2/\rho) \cdot (1/S)$$

$$V = (2 \cdot W/(\rho \cdot S)/(C_{D0}/(3 \cdot k))^{1/2})^{1/2} = V_{Rmax}$$

$$\varepsilon = (4/3)^{1/2} \cdot 2 \cdot (C_{D0} \cdot k)^{1/2} = \varepsilon_{Rmax} \quad 3.$$

$$V = (2 \cdot W/(\rho \cdot S))^{1/2}/(C_{D0}/(3 \cdot k))^{1/4}$$

$$V/\varepsilon = (2 \cdot W/(\rho \cdot S))^{1/2}/((C_{D0}/(3 \cdot k))^{1/4} \cdot (4/3)^{1/2} \cdot 2 \cdot (C_{D0} \cdot k)^{1/2})$$

$$V/\varepsilon = (2 \cdot W/(\rho \cdot S))^{1/2}/((C_{D0}/(3 \cdot k))^{1/4} \cdot (4/3)^{1/2} \cdot 2 \cdot ((C_{D0} \cdot k)^2)^{1/4})$$

$$V/\varepsilon = (2 \cdot W/(\rho \cdot S))^{1/2}/(((C_{D0}/(3 \cdot k)) \cdot (C_{D0}^2 \cdot k^2))^{1/4} \cdot (4/3)^{1/2} \cdot 2)$$

$$V/\varepsilon = (2 \cdot W/(\rho \cdot S))^{1/2}/((4/3)^{1/2} \cdot 2 \cdot ((1/3) \cdot (C_{D0}^3 \cdot k))^{1/4}) = (V/\varepsilon)_{Rmax} \quad (79)$$

re. study phase 8, page 3

Flying performance:

$$R = (1 - W_E/W_{\max} - W_{\text{Pay}}/W_{\max}) \cdot (1/\text{SFC}) \cdot (1/(C_D/C_L)) \cdot V \quad (6)$$

V (km/h)

$$k_R = (1 - W_E/W_{\max} - W_{\text{Pay}}/W_{\max}) \cdot (1/\text{SFC})$$

$$R_{T_{\max}} = k_R \cdot (V/\epsilon)_{T_{\max}} \cdot 3.6 \quad (76)$$

$$R_{\max} = k_R \cdot (V/\epsilon)_{R_{\max}} \cdot 3.6 \quad (77)$$

V (m/s)

$$R_{\max}/R_{T_{\max}} = (V/\epsilon)_{R_{\max}}/(V/\epsilon)_{T_{\max}}$$

$$(V/\epsilon)_{R_{\max}}/(V/\epsilon)_{T_{\max}} = \frac{(2 \cdot W/(\rho \cdot S))^{1/2}/((4/3)^{1/2} \cdot 2 \cdot ((1/3) \cdot (C_{D0}^3 \cdot k))^{1/4})}{(2 \cdot W/(\rho \cdot S))^{1/2}/(2 \cdot (C_{D0}^3 \cdot k)^{1/4})}$$

$$(V/\epsilon)_{R_{\max}}/(V/\epsilon)_{T_{\max}} = \frac{(2 \cdot W/(\rho \cdot S))^{1/2}/((4/3)^{1/2} \cdot (1/3)^{1/4} \cdot 2 \cdot (C_{D0}^3 \cdot k)^{1/4})}{(2 \cdot W/(\rho \cdot S))^{1/2}/(2 \cdot (C_{D0}^3 \cdot k)^{1/4})}$$

$$(V/\epsilon)_{R_{\max}}/(V/\epsilon)_{T_{\max}} = 1/((4/3)^{1/2} \cdot (1/3)^{1/4})$$

$$(V/\epsilon)_{R_{\max}}/(V/\epsilon)_{T_{\max}} = 1/((16/9)^{1/4} \cdot (1/3)^{1/4})$$

$$(V/\epsilon)_{R_{\max}}/(V/\epsilon)_{T_{\max}} = 1/(16/27)^{1/4} = (27/16)^{1/4}$$

$$(V/\epsilon)_{R_{\max}}/(V/\epsilon)_{T_{\max}} = (27/16)^{1/4}$$

$$(V/\epsilon)_{R_{\max}} = (27/16)^{1/4} \cdot (V/\epsilon)_{T_{\max}}$$

$$R_{\max}/R_{T_{\max}} = (27/16)^{1/4} \quad (80)$$

re. study phase 8, page 3

Flying performance:

Maximum flying time:

$$C_D = k_{Tmax} \cdot C_L^2 \quad (81)$$

$$C_D = C_{D0} + k_{P1} \cdot C_L^2$$

$$C_D = 2 \cdot C_{D0}$$

$$C_{D0} = k_{P1} \cdot C_L^2$$

$$C_D = 2 \cdot k_{P1} \cdot C_L^2$$

$$k_{Tmax} \cdot C_L^2 = 2 \cdot k_{P1} \cdot C_L^2$$

$$k_{Tmax} = 2 \cdot k_{P1} \quad (82)$$

Maximum range :

$$C_D = k_{Rmax} \cdot C_L^2 \quad (83)$$

$$C_D = C_{D0} + k_{P1} \cdot C_L^2$$

$$C_D = (4/3) \cdot C_{D0}$$

$$(4/3) \cdot C_{D0} = C_{D0} + k_{P1} \cdot C_L^2$$

$$k_{P1} \cdot C_L^2 = (4/3) \cdot C_{D0} - C_{D0} = (1/3) \cdot C_{D0}$$

$$C_D = 4 \cdot k_{P1} \cdot C_L^2$$

$$k_{Rmax} \cdot C_L^2 = 4 \cdot k_{P1} \cdot C_L^2$$

$$k_{Rmax} = 4 \cdot k_{P1} \quad (84)$$

re. study phase 8, page 3

Zero drag for fuselage body, engine gondola and landing gear:

$$C_{D0} = 1/(1 + a \cdot (l/d)) \quad \text{assumption}$$

$$1 + a \cdot (l/d) = 1/C_{D0}$$

$$a = (1/C_{D0} - 1)/(l/d)$$

$$C_{D0} = 0.16 ; l/d = 1 \quad \text{data for a sphere}$$

$$a = (1/0.16 - 1)/1 = 5.25$$

$$l/d = 1$$

$$C_{D0} = 1/(1 + 5.25 \cdot 1) = 0.16 \quad \text{sphere}$$

$$l/d = 0$$

$$C_{D0} = 1/(1 + 5.25 \cdot 0) = 1 \quad \text{circular plate}$$

$$l/d = \infty$$

$$C_{D0} = 1/(1 + 5.25 \cdot \infty) = 0 \quad \text{long rod}$$

$$C_{D0, \text{fuselage body}} = 1/(1 + a \cdot (l/d)_{\text{fuselage}}) \quad (85)$$

$$C_{D0, \text{engine gondola}} = 1/(1 + a \cdot (l/d)_{\text{engine gondola}}) \quad (86)$$

$$a = 5.25 \quad (87)$$

$$\Delta C_{D0, \text{landing gear}} = C_{D0, P1} \quad (89)$$

$$C_{D0, P1, \text{landing gear outside}} = C_{D0, P1} + \Delta C_{D0, \text{landing gear}} = 2 \cdot C_{D0, P1} = 0.03$$

$$C_{D0, P4, \text{landing gear outside}} = C_{D0, P4} + 2 \cdot \Delta C_{D0, \text{landing gear}}$$

$$\Delta C_{D0, P4, \text{landing gear}} = 2 \cdot \Delta C_{D0, \text{landing gear}}$$

$$C_{D0, P4, \text{landing gear outside}} = C_{D0, P4} + 2 \cdot C_{D0, P1} = 0.0225 + 0.03 = 0.0525$$

re. study phase 10 and 10a, page 2

Ranges with maximum payload:

$$W = W_{\max}$$

$$(V/\varepsilon)_{R\max} = (2 \cdot W_{\max}/(\rho \cdot S))^{1/2} / ((4/3)^{1/2} \cdot 2 \cdot ((1/3) \cdot (C_{D0}^3 \cdot k))^{1/4}) \quad (95)$$

$$(V/\varepsilon)_{T\max} = (2 \cdot W_{\max}/(\rho \cdot S))^{1/2} / (2 \cdot (C_{D0}^3 \cdot k)^{1/4}) \quad (96)$$

$$k_R = (1 - W_E/W_{\max} - W_{Pay}/W_{\max})/SFC \quad (97)$$

$$T = (1 - W_E/W_{\max} - W_{Pay}/W_{\max}) \cdot (1/SFC) \cdot (1/(C_D/C_L)) \quad (5)$$

$$W_{Fuel}/W_{\max} = 1 - W_E/W_{\max} - W_{Pay}/W_{\max}$$

$$W_{Fuel}/W_{\max} = SFC \cdot (C_D/C_L) \cdot T \quad (3)$$

$$\varepsilon = (C_D/C_L)$$

$$(W_{Fuel}/W_{\max})_{\text{hold}} = \varepsilon \cdot SFC \cdot T_{\text{hold}} \quad (99)$$

$$R_{\text{hold}} = (W_{Fuel}/W_{\max})_{\text{hold}}/SFC \cdot (V/\varepsilon)_{R\max} \cdot 3.6 \quad (98)$$

$$R_{\max} = k_R \cdot (V/\varepsilon)_{R\max} \cdot 3.6 = R \quad (91)$$

$$R_{\text{less reserves}} = R - \Delta R - R_{\text{hold}} = R - R_{\text{hold}} - \Delta R \quad (92)$$

$$R_{T\max} = k_R \cdot (V/\varepsilon)_{T\max} \cdot 3.6 = R \cdot (16/27)^{1/4} \quad (93)$$

$$R_{T\max, \text{less reserves}} = (R - R_{\text{hold}}) \cdot (16/27)^{1/4} - \Delta R \quad (94)$$

re. study phase 10 and 10a, page 2

Ferry ranges:

$$(V/\varepsilon)_{R_{\max, \text{Ferry}}} = (V/\varepsilon)_{R_{\max}} \quad (104)$$

$$(V/\varepsilon)_{T_{\max, \text{Ferry}}} = (V/\varepsilon)_{T_{\max}} \quad (105)$$

$$k_{R, \text{Ferry}} = (1 - W_E/W_{\max} - W_{\text{Pay, Ferry}}/W_{\max})/\text{SFC} \quad (108)$$

$$W_{\text{Pay, Ferry}} = 0$$

$$k_{R, \text{Ferry}} = (1 - W_E/W_{\max})/\text{SFC} \quad (106)$$

$$W_{\max} = W \quad (107)$$

$$T_{\text{Ferry}} = (1 - W_E/W_{\max} - W_{\text{Pay, Ferry}}/W_{\max}) \cdot (1/\text{SFC}) \cdot (1/(C_D/C_L)) \quad (5a)$$

$$(W_{\text{Fuel}}/W_{\max})_{\text{Ferry}} = 1 - W_E/W_{\max} - W_{\text{Pay, Ferry}}/W_{\max}$$

$$(W_{\text{Fuel}}/W_{\max})_{\text{Ferry}} = \text{SFC} \cdot (C_D/C_L) \cdot T_{\text{Ferry}} \quad (3a)$$

$$\varepsilon = (C_D/C_L)$$

$$(W_{\text{Fuel}}/W_{\max})_{\text{hold}} = \varepsilon \cdot \text{SFC} \cdot T_{\text{hold}} \quad (99)$$

$$R_{\text{hold}} = (W_{\text{Fuel}}/W_{\max})_{\text{hold}}/\text{SFC} \cdot (V/\varepsilon)_{R_{\max, \text{Ferry}}} \cdot 3.6$$

$$R_{\max, \text{Ferry}} = k_{R, \text{Ferry}} \cdot (V/\varepsilon)_{R_{\max, \text{Ferry}}} \cdot 3.6 = R_{\text{Ferry}} \quad (100)$$

$$R_{\text{less reserves, Ferry}} = R_{\text{Ferry}} - \Delta R - R_{\text{hold}} = R_{\text{Ferry}} - R_{\text{hold}} - \Delta R \quad (101)$$

$$R_{T_{\max, \text{Ferry}}} = k_{R, \text{Ferry}} \cdot (V/\varepsilon)_{T_{\max, \text{Ferry}}} \cdot 3.6 = R_{\text{Ferry}} \cdot (16/27)^{1/4} \quad (102)$$

$$R_{T_{\max, \text{less reserves, Ferry}}} = (R_{\text{Ferry}} - R_{\text{hold}}) \cdot (16/27)^{1/4} - \Delta R \quad (103)$$

re. study phase 10 and 10a, page 3

Zero drag for different aircraft categories:

$$F = A_I \cdot \rho \cdot V^2$$

$$F = W_{\max} \cdot \varepsilon$$

$$W_{\max} = L$$

$$L = (C_{D0}/k)^{1/2} \cdot (\rho/2) \cdot V^2 \cdot S$$

$$\varepsilon = 2 \cdot (C_{D0} \cdot k)^{1/2}$$

$$A_I \cdot \rho \cdot V^2 = W_{\max} \cdot \varepsilon$$

$$A_I \cdot \rho \cdot V^2 = (C_{D0}/k)^{1/2} \cdot (\rho/2) \cdot V^2 \cdot S \cdot 2 \cdot (C_{D0} \cdot k)^{1/2}$$

$$A_I = (C_{D0}/k)^{1/2} \cdot (C_{D0} \cdot k)^{1/2} \cdot S$$

$$A_I = (C_{D0}^2)^{1/2} \cdot S = C_{D0} \cdot S$$

$$C_{D0} = A_I/S \quad (109)$$

$$A_I = n_{\text{engine}} \cdot A_{I,n}$$

$$C_{D0} = n_{\text{engine}} \cdot A_{I,n}/S \quad (110a)$$

$$A_I = 3 \cdot A_{I,3}$$

$$C_{D0} = 3 \cdot A_{I,3}/S \quad (111a)$$

$$A_I = n_{\text{engine}} \cdot 3 \cdot A_{I,3,n}$$

$$C_{D0} = n_{\text{engine}} \cdot 3 \cdot A_{I,3,n}/S \quad (112a)$$

$$A_I = (V_2/V_1) \cdot A_{I,v2/v1}$$

$$C_{D0} = (V_2/V_1) \cdot A_{I,v2/v1}/S \quad (113a)$$

$$A_I = n_{\text{engine}} \cdot (V_2/V_1) \cdot A_{I,v2/v1,n}$$

$$C_{D0} = n_{\text{engine}} \cdot (V_2/V_1) \cdot A_{I,v2/v1,n}/S \quad (114a)$$

$$A_I = (V_2/V_1) \cdot (A_{I1}/A_{I2}) \cdot A_{I2,v2/v1}$$

$$C_{D0} = (V_2/V_1) \cdot (A_{I1}/A_{I2}) \cdot A_{I2,v2/v1}/S \quad (115a)$$

$$A_I = n_{\text{engine}} \cdot (V_2/V_1) \cdot (A_{I1}/A_{I2}) \cdot A_{I2,v2/v1,n}$$

$$C_{D0} = n_{\text{engine}} \cdot (V_2/V_1) \cdot (A_{I1}/A_{I2}) \cdot A_{I2,v2/v1,n}/S \quad (116a)$$

re. study phase 11, page 3

Scaling the configurations:

$$W_{\max}/W_{\text{spec}} = V_{0, \text{aeroplane}} \quad (121)$$

$$h_{0, \text{aeroplane}}^3 = W_{\max}/W_{\text{spec}} \quad (122)$$

$$(W_{\max}/W_{\text{spec}}) \cdot n = V_{0, \text{aeroplane, scale}} \quad (123)$$

$$h_{0, \text{aeroplane, n}}^3 = (W_{\max}/W_{\text{spec}}) \cdot n \quad (124)$$

$$k_{\text{scale}} = n^{1/3} \quad (125)$$

$$(W_{\max}/W_{\text{spec}}) \cdot n_{\text{general}} = V_{0, \text{aeroplane, scale, general}} \quad (127)$$

$$h_{0, \text{aeroplane, genal}}^3 = (W_{\max}/W_{\text{spec}}) \cdot n_{\text{general}} \quad (128)$$

$$k_{\text{scale, general}} = n_{\text{general}}^{1/3} \quad (129)$$

$$k_{\text{scale}} = f(W_{\max, \text{scale}}) = f(W_{\max} \cdot n) \quad (131)$$

$$k_{\text{scale, general}} = f(W_{\max, \text{scale}}) = f(W_{\max} \cdot n_{\text{general}}) \quad (132)$$

re. study phase 11, page 3

Scaling the configurations:

$$S = c \cdot b_S$$

$$S_n = c \cdot k_{scale} \cdot b_S \cdot k_{scale}$$

$$S_n = (c \cdot b_S) \cdot k_{scale}^2 = S \cdot k_{scale}^2$$

$$W/S = W_{max}/S$$

$$(W_{max}/S)_n = n \cdot W_{max}/S_n$$

$$(W_{max}/S)_n = n \cdot W_{max}/(S \cdot k_{scale}^2)$$

$$(W_{max}/S)_n = (W_{max}/S) \cdot (n/k_{scale}^2)$$

$$k_{scale} = n^{1/3}$$

$$(n/k_{scale}^2) = n/n^{2/3} = n^{1/3}$$

$$(W_{max}/S)_n = (W_{max}/S) \cdot n^{1/3} = (W_{max}/S) \cdot k_{scale} \quad (133)$$

$$(W/S)_n = (W/S) \cdot k_{scale}$$

$$(W_{max}/S)_{scale} = (W_{max}/S) \cdot n_{general}^{1/3} = (W_{max}/S) \cdot k_{scale, general} \quad (134)$$

re. study phase 12, page 1, 2 and 3

Ranges and flying height:

$$R = (1 - W_E/W_{\max} - W_{\text{Pay}}/W_{\max}) \cdot (1/\text{SFC}) \cdot (1/(C_D/C_L)) \cdot V \quad (6)$$

$$C_D/C_L = \varepsilon$$

$$(1/(C_D/C_L)) \cdot V = V/\varepsilon$$

$$R = (1 - W_E/W_{\max} - W_{\text{Pay}}/W_{\max}) \cdot (1/\text{SFC}) \cdot (V/\varepsilon)$$

$$R_{T_{\max}} = (1 - W_E/W_{\max} - W_{\text{Pay}}/W_{\max}) \cdot (1/\text{SFC}) \cdot (V/\varepsilon)_{T_{\max}} \cdot 3.6 \quad (135)$$

$$R_{R_{\max}} = (1 - W_E/W_{\max} - W_{\text{Pay}}/W_{\max}) \cdot (1/\text{SFC}) \cdot (V/\varepsilon)_{R_{\max}} \cdot 3.6 \quad (136)$$

V (m/s)

$$V = (2 \cdot W_{\max}/(\rho \cdot S))^{1/2}$$

$$V = f(h) = (2 \cdot W_{\max}/(\rho_h \cdot S))^{1/2} = (2 \cdot W_{\max}/(\rho \cdot S))^{1/2} \cdot (\rho/\rho_h)^{1/2}$$

$$(V/\varepsilon)_{T_{\max}, h} = f(h) = (V/\varepsilon)_{T_{\max}} \cdot (\rho/\rho_h)^{1/2} \quad (137)$$

$$(V/\varepsilon)_{R_{\max}, h} = f(h) = (V/\varepsilon)_{R_{\max}} \cdot (\rho/\rho_h)^{1/2} \quad (138)$$

Zero drag and wave drag:

$$\Delta C_{D0, \text{wave drag}} = (M - 0.8) \cdot 40 \cdot C_{D0, \text{without wave drag}} \quad (143)$$

$$M = 0.8$$

$$\Delta C_{D0, \text{wave drag}} = (0.8 - 0.8) \cdot 40 \cdot C_{D0, \text{without wave drag}} = 0$$

$$M = 1.0$$

$$\Delta C_{D0, \text{wave drag}} = (1.0 - 0.8) \cdot 40 \cdot C_{D0, \text{without wave drag}} = 8 \cdot C_{D0, \text{without wave drag}}$$

$$C_{D0} = C_{D0, \text{without wave drag}} + \Delta C_{D0, \text{wave drag}}$$

$$C_{D0} = C_{D0, \text{without wave drag}} + (M - 0.8) \cdot 40 \cdot C_{D0, \text{without wave drag}}$$

$$C_{D0} = C_{D0, \text{without wave drag}} \cdot (1 + (M - 0.8) \cdot 40) \quad (142)$$

re. study phase 12, page 3

Mean and maximum thrust:

$$F = A_I \cdot \rho \cdot V \cdot (V_J - V_I)$$

$$V_J = 2 \cdot V_I$$

$$V_I = V$$

$$F = A_I \cdot \rho \cdot V \cdot (2 \cdot V_I - V_I) = A_I \cdot \rho \cdot V \cdot V$$

$$F_{\text{mean, 1 engine}} = A_I \cdot \rho \cdot V^2 \quad (144)$$

$$V_J = 3 \cdot V_I$$

$$V_I = V$$

$$F = A_I \cdot \rho \cdot V \cdot (3 \cdot V_I - V_I) = A_I \cdot \rho \cdot V \cdot (2 \cdot V)$$

$$F_{\text{max, 1 engine}} = A_I \cdot \rho \cdot V^2 \cdot 2 = 2 \cdot F_{\text{mean, 1 engine}}$$

$$F = 2 \cdot A_I \cdot \rho \cdot V^2 \cdot 2 = 4 \cdot A_I \cdot \rho \cdot V^2$$

$$F_{\text{mean, 1 engine}} = F_{\text{mean, 2 engines}}$$

$$F_{\text{max, 2 engines}} = 4 \cdot F_{\text{mean, 1 engine}} = 4 \cdot F_{\text{mean, 2 engines}} \quad (145)$$

Wave drag compensated by maximum thrust:

$$C_{D01} = A_I/S$$

$$C_{D02} = 4 \cdot A_I/S$$

$$\Delta C_{D0} = C_{D02} - C_{D01} = 4 \cdot A_I/S - A_I/S = 3 \cdot (A_I/S)$$

$$C_{D0, \text{without wave drag}} = A_I/S$$

$$\Delta C_{D0, \text{wave drag}} = 3 \cdot (A_I/S) = 3 \cdot C_{D0, \text{without wave drag}} \quad (146)$$

re. study phase 13, page 1 and 2

Range factors:

$$k_R = (1 - W_E/W_{\max} - W_{\text{Pay}}/W_{\max})/SFC \quad (97)$$

$$W_E/W_{\max} = 0.5$$

$$SFC = 0.8$$

$$W_{\text{Pay}}/W_{\max} = 0.25$$

$$k_R = (1 - 0.5 - 0.25)/0.8 = 0.3125 \text{ lbf} \cdot \text{h/lb} \quad \text{Medium range transport}$$

$$W_{\text{Pay}}/W_{\max} = 0.375$$

$$k_R = (1 - 0.5 - 0.375)/0.8 = 0.15625 \text{ lbf} \cdot \text{h/lb} \quad \text{Short range transport}$$

$$W_{\text{Pay}}/W_{\max} = 0.125$$

$$k_R = (1 - 0.5 - 0.125)/0.8 = 0.46875 \text{ lbf} \cdot \text{h/lb} \quad \text{Long range transport}$$

$$W_{\text{Pay}}/W_{\max} = 0$$

$$k_R = (1 - 0.5 - 0)/0.8 = 0.625 \text{ lbf} \cdot \text{h/lb} \quad \text{Ferry flight}$$

$$R_{\max}/R_{T\max} = (27/16)^{1/4} \quad (80)$$

$$R_{\max} = (27/16)^{1/4} \cdot R_{T\max} = 1.13975 \cdot R_{T\max} \quad (148)$$

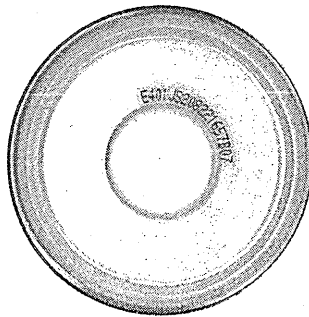
$$R_{\max, \text{M.R.T.}} = 1.13975 \cdot R_{T\max, \text{M.R.T.}}$$

$$R_{\max, \text{S.R.T.}} = 1.13975 \cdot R_{T\max, \text{S.R.T.}}$$

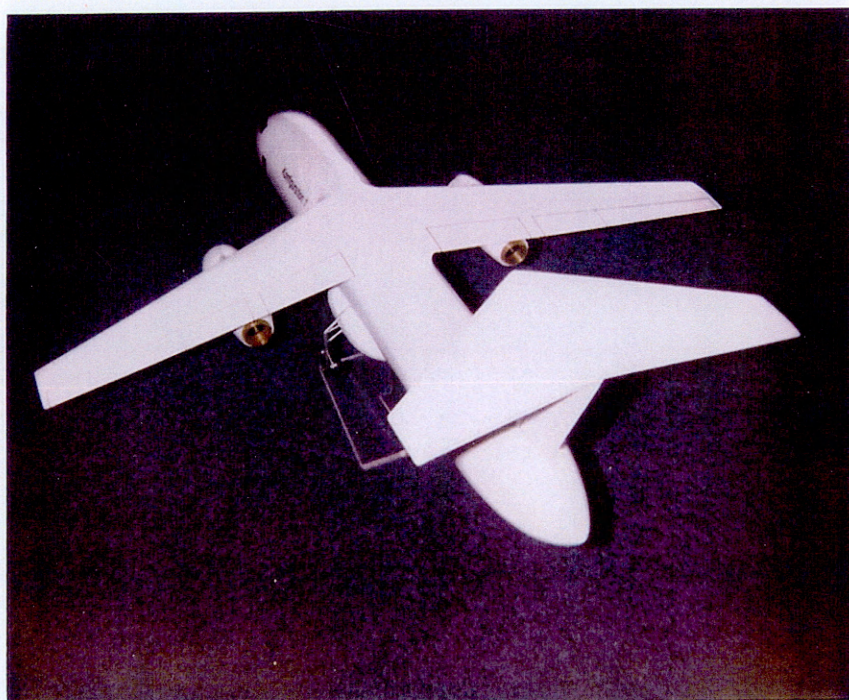
$$R_{\max, \text{L.R.T.}} = 1.13975 \cdot R_{T\max, \text{L.R.T.}}$$

$$R_{\max, \text{F.Fl.}} = 1.13975 \cdot R_{T\max, \text{F.Fl.}}$$

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Programme / Programs:
CW02TAB KONFPRINZ1
CW02TAB2 KONFPRINZ1A
CW02TAB4 KONFPRINZ1B
CW02TAB5 ROLLSTRECKE



Two photos of a more exact Configuration 1

340 b