Independent Review of the In-Service ADF Combat Boot: Technical Report

Defence Materiel Organisation

Melbourne
19th March 2008

Booz | Allen | Hamilton

FOREWORD

Booz Allen has been tasked by the Defence Materiel Organization to undertake a study of the Combat Boot issued to members of the Australian Defence Force. This task arose from an earlier study, the ADF Clothing Review of May 2006 which recommended an "independent review of the boot and its fitment, including independent expert podiatry advice".

To complete this study, Booz Allen established a team of specialists, with a combination of podiatry, podiatric surgery and podorthic specialist skills, and relevant military experience. The team was completely independent, having no commercial or other link to either manufacturers of the Boot, or the DMO agencies responsible for its procurement.

Two Reports have been produced. The Executive Report provides a brief overview of the Review and its findings and conclusions. This Technical Report provides a comprehensive report into the Review and its findings, with relevant data and analysis contained in the supporting Annexes.

The team is pleased to be able to present this Technical Report to the Commonwealth, and hopes that it will contribute to the goal of ensuring that ADF personnel continue to be provided with equipment which meets the endorsed requirements and is fit for the function for which it has been acquired.

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Project Director, ADF Combat Boot Review Team
Booz Allen Hamilton
Canberra
19th March 2008

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1 Executive Summary

The Commonwealth contracted Booz Allen Hamilton to conduct an independent assessment of the Australian Defence Force (ADF) Combat Boot. This assessment emanated from the ADF Clothing Review of May 2006 which recommended "an independent review of the Boot and its fitment, including independent expert podiatry advice".

The Statement of Work (SOW) provided by the Defence Materiel Organisation (DMO) contained eight very specific Review Criteria,

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The Review determined that there is no universally accepted definition of "function" nor "fitness for function", and that while industry standards and practice give some guidelines, particularly in terms of sporting and safety footwear, they do not address the unique requirements of the military Combat Boot. The Review noted that there are terms such as "fitness for service" (which is defined within Defence technical regulatory publications and is the basis of assessing products against an endorsed user requirement) and "fitness for purpose" which is also frequently used, but which is not defined.

The Review therefore set out to define "function" and "fitness for function" for the purposes of this review.

The Review recognized that the purpose of the Combat Boot is to "support and protect the foot of the dismounted combat soldier". The Review used this to develop a definition of the 'function' of the Combat Boot as *'the Combat Boot is to provide climatic natural occupational and limited impact protection for the feet of the dismounted combat soldier in circumstances relevant to operational and training employment in the field'*. The key elements of this definition are the focus on the dismounted combat soldier (which directly includes the issue of the combat load carried by the dismounted soldier) and the operational nature of the task on which the soldier is engaged.

The Review identified two sets of evaluation criteria. The first was a list of functional characteristics, drawn from the Review's examination of existing Commonwealth documentation, relevant literature and consideration by the subject matter experts of the Review. This resulted in establishing the

functional characteristics for the baseline on which to assess "fitness for function" for this review.

The second set was a list of user requirements, drawn solely from the Statement of Requirement) and, which where possible, were requirements that could be empirically tested.

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The pertinent Review outcomes are discussed in Section 4 of this Report. A consolidated summary of all Review findings are collated in Section 5 under the respective Review criteria, with the Report Conclusions at Section 6, and a proposed way forward is provided at Section 7.

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2 Background

"A soldier in shoes is only a soldier; but in boots, he becomes a warrior."
General George S. Patton

"The 'poor bloody infantry' have had to trust their feet and thus their lives to their boots in every war, ... The Romans, using sandals, performed very poorly in cold climates... Almost every military action since 1700, when doctors started to take a real interest in the health of the troops, has highlighted the seriousness of foot disorders produced by the failure of boots to perform as required."
(Howard & Oakley, 1984)

2.1 Introduction

The Terra Combat Boot was introduced into service in 1999 as the replacement for the General Purpose (GP) Boot.

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The functional requirements for the combat boot were extensive. The expectations of the users, were for a boot that generally would enhance the wearer's movement, provide protection and minimise lower limb injuries and be comfortable. The primary user was identified as the dismounted combat soldier. A number of specific functional and design requirements were included such as colour, water and heat resistance, breathability, weight, penetration resistance, durability and shelf life amongst many others.

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Considerable research and development has been undertaken into footwear worldwide, especially into sports footwear since the 1970's. It is worthy of note that there is not one shoe for all sports today but a number of different shoes, and in the case of running, a number of shoes to suit the individual, the purpose and environment in which the shoe is to be used. There is also a body of research literature specifically addressing the biomechanical requirements of military combat boots. This literature was reviewed by the Team and was used to assist with developing the "fitness for function" criteria.

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This established knowledge should be considered for its application to gain a better understanding of the design and development, and assessment of a combat boot.

To assist readers of this report a brief introduction to Foot Anatomy, Footwear and Fit is included at

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2.2 Terms of Reference

Booz Allen Hamilton was tasked by DMO to conduct an independent review of the ADF Combat Boot. This review follows the ADF Clothing Review of May 2006, conducted on behalf of the Minister of Defence, which included a recommendation (No 22) that required an "independent review of the boot and its fitment, including independent expert podiatry advice".

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The stated scope of the task was *"to assess and document the fitness of function of the ADF combat boot using independent expert podiatry advice."*

2.3 Report Structure

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2.4 Combat Boot Development

The role of the combat boot is often little recognised for the impact it can have on the soldiers' performance. Under ideal circumstances, the development of

a combat boot should involve a systematic process including identification of the requirements of "fitness for function". This may seem surprising and unnecessarily complicated but the nature of a boot, especially one for such a demanding role, is such that many requirements will conflict and compromises will have to be made. An iterative process would allow these compromises to be judged such that ultimately the requirements are optimised and prioritised. The process would start with the definition of the functional characteristics and determination of the methods for measurement of those characteristics. A number of boots could be compared to refine the preferred characteristics even further. It would be necessary to collect anthropometric data from a significant sample of the intended boot population, decisions would be made on the requirements for the footwear, materials and its design. A number of Last designs could be compared to determine the best Last shape to satisfy fit requirements.

The next step would be a series of 'bench top' experiments to test different boot design parameters and materials. Once suitable design(s) have been developed, human factors testing in a biomechanics laboratory on a very limited production run of the boot(s) with the design parameters that the 'bench top' testing deemed appropriate. This testing, will then inform further development before more bench top testing in an iterative process until the optimal design and performance criteria are identified. The next step in the process would be controlled field trials; the results of which could be fed into a further iterative process between 'bench top' and human factors testing before a final field trial. Some discussion and examples of the range and nature of qualitative trials are included The final step in the process would be through surveillance and monitoring of the final 'roll out' of the "ideal" boot and its specification. This process concept is summarised in Figure 3 (on the following page).

Although the development process above is designed to produce the "optimised boot", there should also be a subsequent 'in-service management' phase. It is essential that there be a systematic process for continual assessment, quality control and data collection. As circumstances change, requirements may be modified. Changes should be trialled and validated before they are introduced to service.

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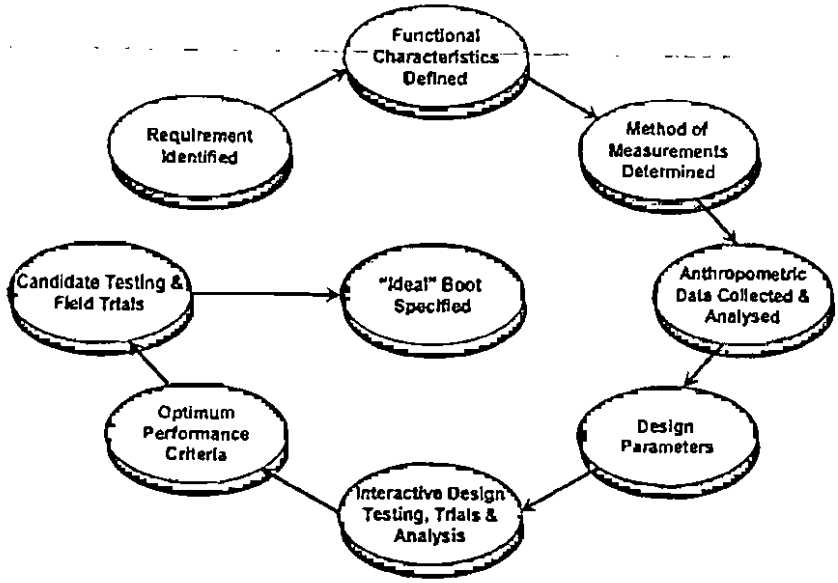

Figure 3. Concept for Combat Boot Development

2.5 Methodology

In conducting the Combat Boot Review, the Review Team was determined to satisfy the requirements contained in the SOW and to report in accordance with the Criteria as identified in Section 3 of the SOW.

Of primary concern to the Review Team was the concept of "fitness for function" as this term is used throughout the SOW Criteria (albeit without definition) and understanding this concept is essential to the assessment of the Combat Boot. It might appear that this is a simple enough exercise for items of clothing including footwear, but this could not be further from the truth. While most wearers would intuitively feel that they understand what is, or is not "fit for function" for their own situation and conditions, there is no universally accepted definition.

Other terms, such as "fit for service" or "fit for purpose", are often used colloquially, and indeed, many use "fit for function/purpose/service" interchangeably. However the Review felt that there were substantive differences between the terms. Notably, "fit for service" is defined in the Technical Regulatory Authority Materiel Manual (TRAMM) as "the materiel meets an endorsed operational requirement by virtue of its design and manufacture".

The Review was also highly conscious of the clear direction on the Scope of the Task in the SOW which states at paragraph 2, that "the Review is to assess and document the "fitness of function" of the ADF Combat Boot".

The Review Team therefore set out to define this term, for the purposes of the Review, and applied this definition to the subsequent analysis.

This process commenced with a collaborative effort within the Review team, combining literature research and subject matter expertise, to define the

function of the Combat Boot and then to determine a series of core functional characteristics which would contribute to the "fitness for function" analysis.

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2.5.1 *Defining "Fitness for Function"*

The Review has defined the "function" of the Tropical Climate Combat Boot based on the original user requirement, This definition is as follows:

> The function of the combat boot is to provide climatic, natural, occupational and limited impact protection for the feet of the dismounted combat soldier in circumstances relevant to operational and training employment in the field.

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While 'Fit' is arguably the most important characteristic, the inter-relationships between the characteristics are such that, except possibly for 'Ease of Donning and Doffing' and 'Durability', the Review did not believe further ranking within the groupings was possible. These functional characteristics will be referred to as they apply to particular aspects of the boot assessment undertaken by the Review.

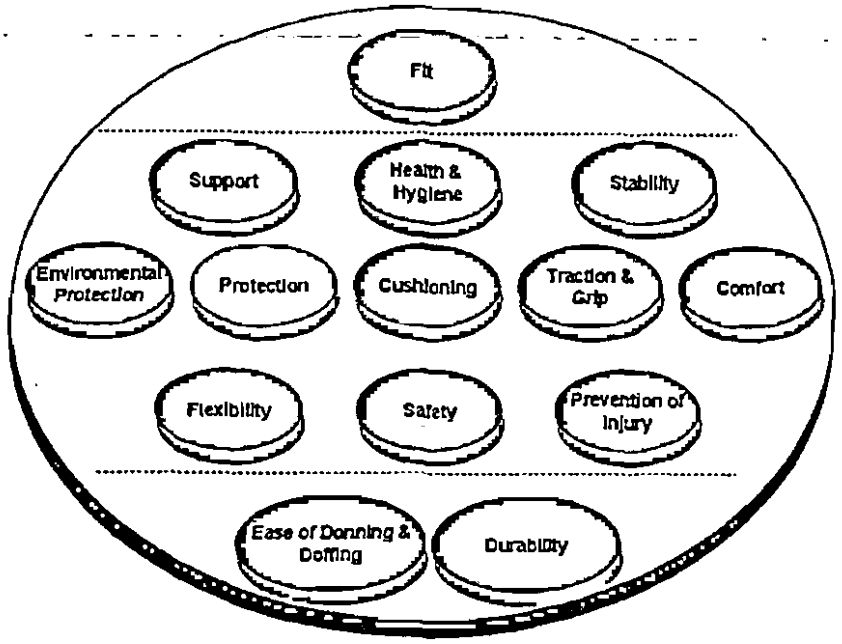

Figure 4. "Fitness for Function" – Functional Characteristics

A brief description of each characteristic is as follows:

- *Fit* is the most important considerations of all footwear characteristics. Fit is the ability of the boot to conform to the size, width, shape and proportions of the foot.
- *Cushioning* is the inherent ability of the combat boot's components to individually, and/or collectively, dissipate the forces the foot and lower limb are exposed to during the stance phase of gait.
- *Support* is the ability of the combat boot to sustain the anatomical integrity of the foot when exposed to a level of intense activity that would normally not be undertaken unshod.
- *Stability* refers to the capacity of the soldier to feel he/she has a level of steadiness or permanence whilst using the combat boot when undertaking intensive levels of activity.
- *Traction and grip* refers to the capacity of the boot to allow the dismounted soldier to minimize slippage and keep his/her feet whilst running, crawling and climbing by imbedding the tread on the outersole into a variety of terrain surfaces.
- *Flexibility* refers to allowing the foot to function as close to its normal performance levels even whilst wearing the combat boot.
- *Protection* is the combat boot's ability to protect the soldier's foot from specified man made threats.
- *Environmental protection* is the combat boot's ability to protect the soldier's foot from climatic and other non-climatic impediments.

- *Health and hygiene* refers to the combat boot's ability to allow the soldier to maintain a healthy and fit foot in operational environments.
- *Comfort* is closely interrelated with Fit and other footwear characteristics. It is a subjective characteristic based on an individual's assessment on how the combat boot 'feels' during use in various environments.
- *Prevention of injury* to the combat boot's ability to prevent injury either from external factors or by the use of the combat boot itself not causing injury either short term or long term to the soldier.
- *Safety* is the combat boot's ability to keep the soldier's foot from harm from specified hazards.
- *Ease of donning and doffing* refers to the ease with which the combat boot can be put on and removed by the soldier.
- *Durability* refers to the combat boot's ability to undergo reasonable 'wear and tear' by a soldier over a specified period.

More detailed definitions of the characteristics adopted by the Review and related boot features are contained The Review recognised that in almost all cases the definition of such criteria is open to interpretation and assessment is highly subjective, but felt that this was unavoidable - as far as the Review is aware, a purely objective assessment of such a matter has never been satisfactorily concluded.

2.5.2 *Assessment Methodology*

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The Review took an approach that was systematic and considered the existing boot, relevant documents, test data, survey analysis and expert assessment. The inputs to assessment applied by the Review are shown in Figure 5 (on the following page).

The Commonwealth provided the Review team with a selection of new and used Terra Combat Boots and the relevant requirements and specification documentation. Additionally, the Review obtained sample socks, and also a number of sets of the current Last from · Initially, the Review set out to measure and assess the materials, design and construction against industry recognised footwear criteria. This meant undertaking a range of laboratory tests (conducted by independent accredited laboratories), reviewing existing test reports, and extensively assessing industry standards and test methodology for occupational footwear. This allowed the Review to understand all aspects of the Terra Combat Boot and identify specific areas of importance to be the focus of further analysis

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The testing plan was designed to focus on those selected issues identified by the Review which could contribute directly to the "fitness for function" analysis. A summary and explanation of the testing undertaken during the Review is

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The Review was also able to interact extensively with a wide variety of stakeholders. This stakeholder engagement took the form of interviews and site visits. A considerable amount of information and advice was freely provided and was of great assistance to the review. A summary of the stakeholder engagement is

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2.6 The Review Team

Details of the Booz Allen review team are provided at Section 8 of this Report.

No members of the Review Team have had any previous involvement with the Terra Combat Boot, either in its development, manufacture or tendering The Review sought to maintain its independence and objectivity throughou its considerations.

2.7 Assumptions and Limitations

2.7.1 *Scope of the Review*

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2.7.2 *Testing*

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To complete this study, Booz Allen established a team of specialists, with a combination of podiatry, podiatric surgery and podorthic specialist skills, and relevant military and footwear industry experience. The team was completely independent, having no commercial or other link to either manufacturers of the Boot, or the DMO agencies responsible for its procurement.

Two Reports have been produced. The Technical Report provides a comprehensive report into the Review and its findings, with relevant data and analysis contained in the supporting Annexes. This Executive Report is intended to provide a briefer overview of the Review and its findings and conclusions.

The team is pleased to be able to present this Executive Report to the Commonwealth, and hopes that it will contribute to the goal of ensuring that ADF personnel continue to be provided with equipment which meets the endorsed requirements and is fit for the function for which it has been acquired.

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Project Director, ADF Combat Boot Review Team
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B. Functional Characteristics of the Combat Boot
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1 Executive Summary

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The Review identified two sets of evaluation criteria. The first was a list of functional characteristics, drawn from the Review's examination of existing Commonwealth documentation, relevant literature and consideration by the subject matter experts of the Review. This resulted in establishing the

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2 Background

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General George S. Patton

"The 'poor bloody infantry' have had to trust their feet and thus their lives to their boots in every war, ... The Romans, using sandals, performed very poorly in cold climates... Almost every military action since 1700, when doctors started to take a real interest in the health of the troops, has highlighted the seriousness of foot disorders produced by the failure of boots to perform as required"
(Howard & Oakley, 1984)

2.1 Introduction

The Terra Combat Boot was introduced into service in 1999 as the replacement for the General Purpose (GP) Boot.

The functional requirements for a combat boot are extensive. The expectations of the user are for a boot that would enhance the wearer's movement, provide protection, minimise lower limb injuries, and be comfortable. The primary user was identified as the dismounted combat soldier. A number of specific user and design requirements were included such as colour, water and heat resistance, breathability, weight, penetration resistance, durability and shelf life amongst many others.

Considerable research and development has been undertaken into footwear worldwide, especially into sports footwear since the 1970's. It is worth noting that there is not one shoe for all sports today but a number of different shoes, some for individual sports, and in many cases, a very wide range of alternatives. There is also a body of research literature specifically addressing

the biomechanical requirements of military combat boots. This research was used by the Review to assist in defining "fitness for function" of the combat boot.

A brief introduction to Foot Anatomy, Footwear and Fit is provided at Annex A for readers not familiar with this specialised field.

2.2 Terms of Reference

Booz Allen Hamilton was tasked by the DMO to conduct an independent review of the ADF Combat Boot. This review follows the ADF Clothing Review of May 2006 which recommended an "independent review of the boot and its fitment, including independent expert podiatry advice".

The stated scope of the task was *"to assess and document the fitness of function of the ADF combat boot using independent expert podiatry advice."*

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2.3 Purpose and Structure of the Executive Report

This Executive Report has been developed for the purpose of providing readers with an overview of the outcomes from the Review conducted by

This Executive Report commences with a brief explanation of the assessment methodology, including the Review's definition of "function" and "fitness for function".

The section on Review Outcomes provides an overview of the assessment against the defined functionality and a list of the key findings. Feedback from the user and industry and suggested near term improvements for the combat boot are included within this section.

The Report concludes with a summary of the conclusions and observations on options for the way ahead.

2.4 Methodology

Of primary concern to the Review Team was the concept of "fitness for function" as this term is used throughout the SOW Criteria (albeit without definition) and understanding this concept is essential to the assessment of the Combat Boot. It might appear that this is a simple enough exercise for items of clothing including footwear, but this could not be further from the truth. While most wearers would intuitively feel that they understand what is, or is not "fit for function" for their own situation and conditions, there is no universally accepted definition.

Other terms, such as "fit for service" or "fit for purpose", are often used colloquially, and indeed, many use "fit for function/purpose/service" interchangeably. However the Review felt that there were substantive differences between the terms. Notably, "fit for service" is defined in the Technical Regulatory Authority Materiel Manual (TRAMM) as "the materiel meets an endorsed operational requirement by virtue of its design and manufacture". The Review felt that this definition assumes that the statement of requirement is accurate and comprehensive, and accurately reflected in the procurement specifications.

The Review was also highly conscious of the clear direction on the Scope of the Task in the SOW which states at paragraph 2, that "the Review is to assess and document the "fitness of function" of the ADF Combat Boot".

The Review Team therefore set out to define this term, for the purposes of the Review, and applied this definition to the subsequent analysis.

This process commenced with a collaborative effort within the Review team, combining literature research and subject matter expertise, to define the function of the Combat Boot and then to determine a series of core functional characteristics which would contribute to the "fitness for function" analysis.

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2.4.1 *Definition of "Fitness for Function"*

The Review identified the purpose of the Boot, as stated in the original user requiremen and expanded this to define the function of the combat boot, for use during this Review. The function of the Boot was defined as:

> The function of the Combat Boot is to provide climatic, natural occupational and limited impact protection for the feet of the dismounted combat soldier in circumstances relevant to operational and training employment in the field.

The Review identified functional characteristics required of a combat boot which would contribute to its achievement of this function in use by a dismounted combat soldier. These "fitness for function" characteristics are shown in Figure 2 below and are broadly grouped into three levels of priority.

While 'Fit' is arguably the most important characteristic, the inter-relationships between the characteristics[1] are such that, except possibly for 'Ease of Donning and Doffing' and 'Durability', the Review did not believe further ranking within the groupings was possible.

A brief description of each of the characteristics including their respective inter-relationships is provided at Annex B.

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[1] For example the interrelated characteristics with Fit are: Comfort, Stability, Support, Flexibility, Safety, Health & Hygiene and Prevention of Injury.

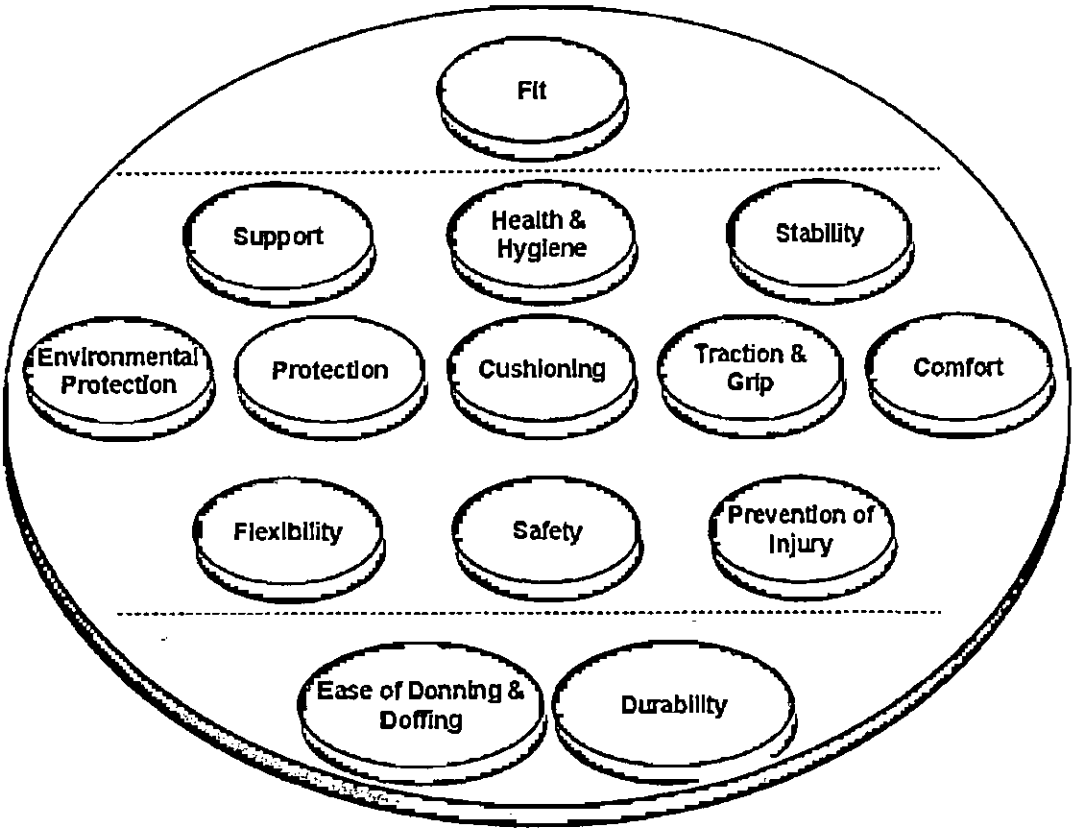

Figure 2. "Fitness for Function" – Functional Characteristics

2.4.2 Review Methodology

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The Review adopted a systematic approach which included considering the existing boot, relevant documents, available and relevant test data, survey analysis, and expert assessment.

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The Commonwealth provided the Review team with a selection of new and used Terra Combat Boots and the relevant requirements and specification documentation. Additionally, the Review obtained sample socks, and also a number of sets of the current Last As a first step, the Review set out to measure and assess the materials, design and construction against industry recognised footwear criteria. This involved a range of laboratory tests (conducted by independent accredited laboratories), reviewing existing test reports, and extensively assessing industry standards and test methodology

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The Review also engaged extensively with a wide variety of stakeholders, including formal interviews and site visits. Significant data and advice was received during this process.

2.5 The Review Team

Details of the Booz Allen review team are provided at Annex C.

No member of the Review Team has had any previous involvement with the Terra Combat Boot, either in its development, manufacture or tendering. The Review sought to maintain its independence and objectivity throughout its considerations.

2.6 Assumptions and Limitations

2.6.1 Scope of the Review

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2.6.4 Specifications

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2.6.5 Testing

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2.6.6 Availability of Data

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3 Review Outcomes

3.1 Overview

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3.2 The MINCS(L) and The Specifications

3.2.1 MINCS(L) Assessment

3.2.2 Specification Assessment

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3.2.4 Overall Assessment

3.3 Assessment of Fitness for Function

3.3.1 Background

The Review undertook quantitative testing and qualitative analysis against the user requirements and capabilities drawn from the Statement of Requirement . The extent and nature of the analysis varied when comparing the selected user requirements and capabilities to the "fitness for function" characteristics:

- Fit was assessed as a specific issue.
- Comfort (except for weight), Cushioning, Stability and Support were considered together.
- Weight was addressed separately.
- Health & Hygiene, Safety and Prevention of Injury were assessed together.
- Three aspects of Protection were assessed: Impact protection, anti-static characteristics and penetration resistance.
- Four aspects of Environmental Protection were assessed: Moisture control, resistance to water, temperature resistance and climatic conditions.
- Only single aspects of Durability, Traction and Flexibility were assessed.
- The assessment of Ease of Donning and Doffing was limited.

3.3.2 Initial Analysis

3.3.2.1 Fit and Size Range

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3.3.2.2 *Durability*

3.3.2.3 *Moisture Control & Resistance*

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3.3.2.4 *Comfort, Support, Cushioning, Biomechanical Support and Shock*

3.3.3 Overall "Fitness for Function" Assessment

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3.4 User and Industry Feedback

3.4.1 User Feedback

The information gathered from the on-line survey, focus groups and RODUMs was analysed and used extensively as qualitative evidence to

3.4.1.1 The On-Line Survey

The Review Team conducted an on-line survey to allow individual members of the ADF the opportunity to provide direct feedback on the Combat Boot.

ANNEX A

FOOT ANATOMY, FOOTWEAR AND FIT

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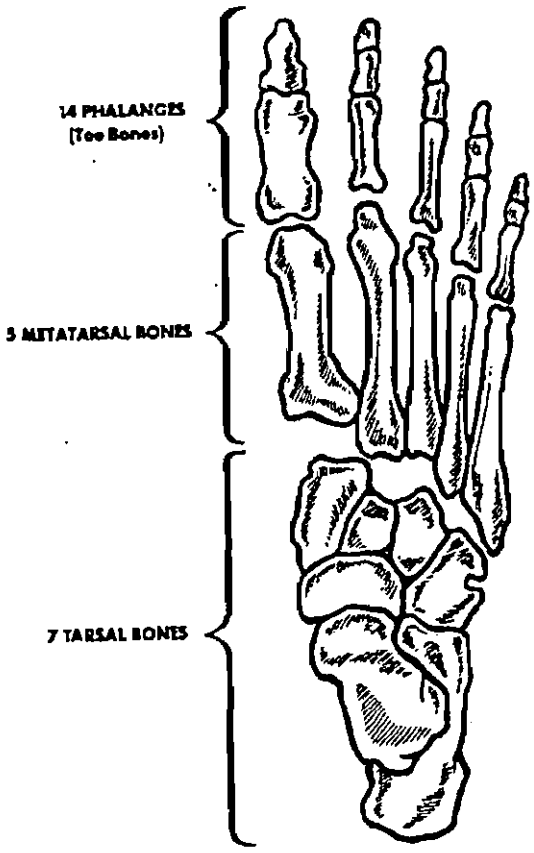
The purpose of this overview is to provide readers with a basic understanding of foot structure and function, footwear structure, function and fit.

Foot Anatomy

The human foot is a complex organ. Each foot consists of 26 bones (the 52 in both feet comprise 1/4 of all the bones in the body). Anatomically the foot can be divided into the rearfoot (the tarsal bones, of which the calcaneus (heel bone) is the largest and bears the weight), and the forefoot. The forefoot consists of the five metatarsal bone and the phalanges (toes). There are two extra bones under the head of the first metatarsal called the sesamoid bones that function like mini knee caps.



Structurally, the foot consists of several arches and 38 joints. The longitudinal arch, which is higher along the medial (inside) than the lateral (outside), is considered the main arch. The transverse arch runs from the outside to inside

in the midfoot (there is no arch across the metatarsal heads). The arches are responsible for a lot of the structural integrity of foot anatomy.

The foot is a complex structure, besides the bones the foot has 19 muscles and tendons, 18 of which are on the sole of the foot. There are 13 leg muscles whose extended tendons are attached to different places in the foot. There are 107 ligaments, far more than any other part of the body of equivalent size. The foot has about 60,000 sweat glands, 120,000 per pair, more than found anywhere else on the body.

Anatomically, there are as many variations in foot anatomy as there are variations in the anatomy of the face. However, the foot with all these variations is expected to function on the same structure (usually a hard surface in footwear).

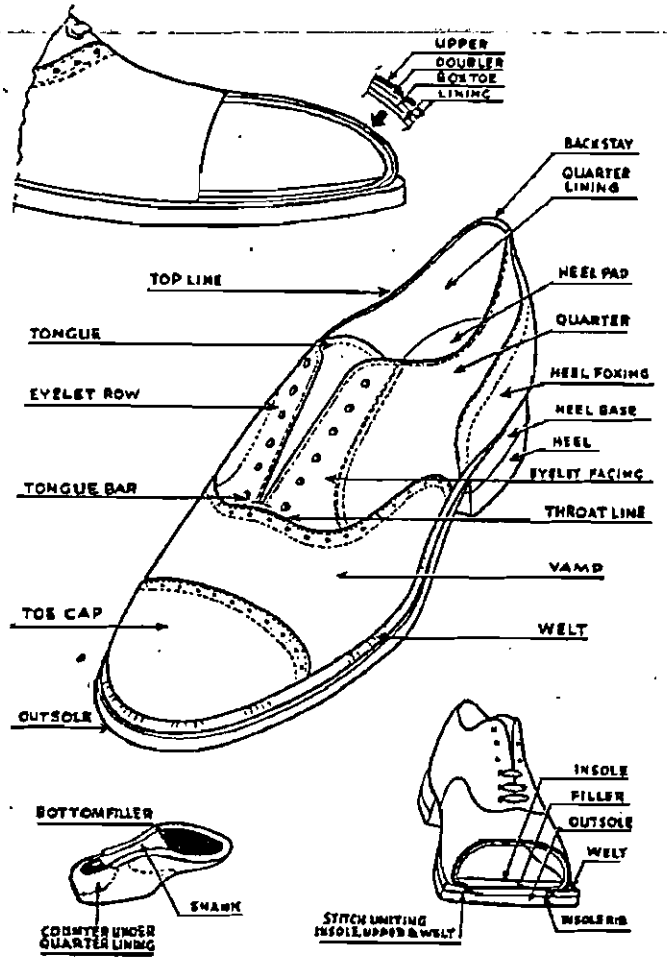
Foot Function

The foot serves a number of functions and carries out those functions as a masterpiece of engineering. During gait (walking), the heel contacts the ground first slight inverted (tipped out at the ankle). After the foot hits the ground it rolls inwards (pronates) to lower the longitudinal arch to help absorb shock and adapt to the terrain. If this pronation motion is excessive, it is considered pathologic. Also, at ground contact the knee and ankle bend to further help absorb shock. After this initial contact, the body moves forward over the foot at the ankle joint. Later in this stance phase, the heel begins to come off the ground; the rearfoot starts to roll outwards (supinate); and the foot bends at the metatarsophalangeal joints (across the ball of foot). All of this is to make the foot more efficient during propulsion.

Essentially at ground contact, the foot become a 'loose bag of bones' to absorb shock and adapt to the different underfoot surfaces; but then transforms into a 'rigid lever' during propulsion. Footwear has to, at least, not interfere with this process and, preferably, facilitate or enhance this process.

Footwear Anatomy

Footwear consists of a number of parts, with the two main parts being the upper and the sole. The upper consists of the quarter (the rear part); the vamp (the fore part); the heel seat (the area the heel sits on); the toe box (the 'roof' of the toe area); the counter (the firm part around the outside of the heel). The sole consists of the outsole (the part that contacts the ground); the insole or foot bed (the part that the foot rests on); the midsole (extra sole material between the outsole and insole). Also embedded in the sole is the shank to give the rear part of the shoe some more stability. In addition to what has been traditionally called the insole or foot bed, there is often a removable insole or foot bed added for comfort. The terms used for these are commonly interchanges and may lead to confusion.



PARTS AND CONSTRUCTION OF A MAN'S GOODYEAR WELT PROCESS

There are many different technologies and methods of attaching the upper unit to the sole unit, such as stitchdown; goodyear weld; cement; slip lasted; and injection moulded. There are advantages and disadvantages of each method.

The materials used in all the different components are many and varied with each material having specific functional characteristics and their own advantages and disadvantages.

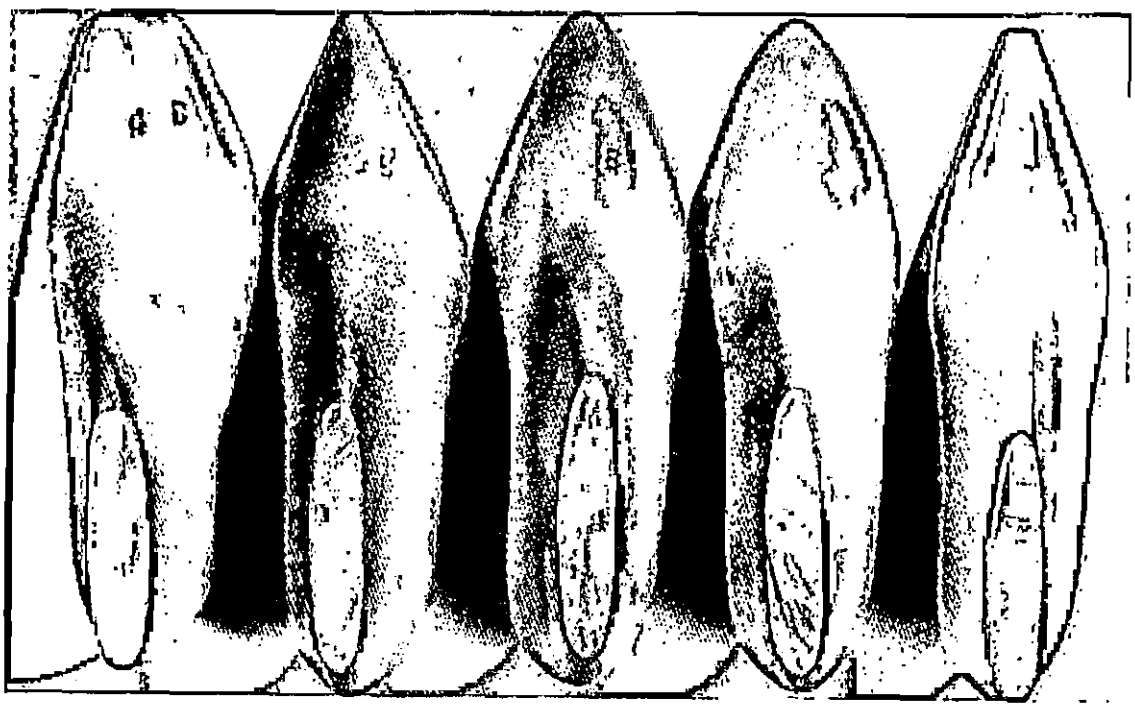
Footwear Function

As the foot is a complex structure that has to meet many demands and has many functions, so the footwear must not hinder and facilitate these functions (unless fashion dictates otherwise). The footwear must be stable where and when the foot is stable; yet the footwear must also be flexible when and where the foot is flexible. It has to achieve this in the context of many different environments and surfaces. And most of all it has to fit and be comfortable.

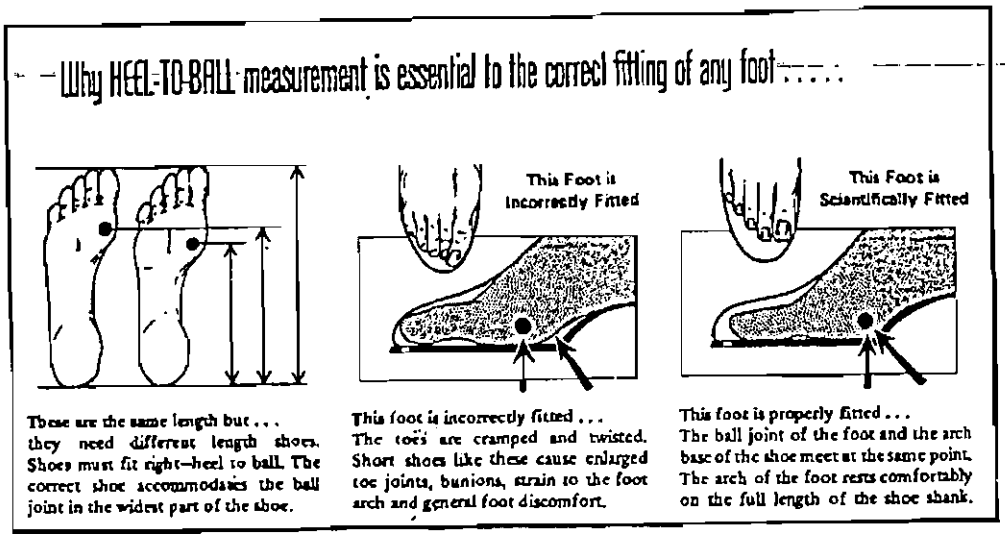
Footwear Fit

Fit is probably one of the most important considerations in footwear, yet is the one area that has no standard metric to measure it, due to the subjective nature of the concept of a good fit. The whole concept of fit is related to the three dimensional shape of the footwear (compared to the foot) and the particular characteristics of footwear function that any particular footwear has. Fit is the ability of the shoe to conform to the size, width, shape and proportions of the foot.

The central component of the three dimensional shape of footwear is the last. The last is the plastic (or wood) model that footwear is manufactured on. Each footwear size will have a different last, but all lasts for each footwear model will have the same ratio of measurements (i.e. the basic last shape). Each model of footwear and each manufacturer will generally have a different last shape that they consider provides the widest range of fit to the population that the footwear model is targeting.



During manufacture, the upper is stretched over the last and the insole board is attached to the upper to hold it in place; the outer sole is then attached (stitched or injection moulded) to this. The last is then removed.



Lasts have many measurements to characterise them (e.g. length, width, heel-to-ball, dorsal height, etc) as well as characteristics to assist with footwear function (e.g. heel height; toe spring, etc). All of these characteristics affect fit and function of the footwear to facilitate and hopefully enhance function of the foot.

There is no such thing as a "perfect" fit. It has been shown time and again that no person has two feet that are the same size, shape, proportions or functional character. In 1945, the US Army commissioned a study of foot measurements. 27 dimensions on both feet of 6,775 men were taken in a massive study. The most important conclusion: "...(to make a new single last to fit all men) may not prove possible since it is evident that consistent or orderly schemes of dimensional inter-relationships applicable to all, or even a majority of men, probably do not exist."

The foot is a dynamic structure and changes in size, shape and proportions. Fitting needs to account for the four phases of fit:

- *Static Fit:* The foot at rest when the customer is seated.
- *Weight bearing Fit:* The fit with the foot bearing weight, as in standing or loaded.
- *Functional Fit:* Fit of the fit under dynamic conditions, such as walking, running, jumping etc.
- *Thermal Fit:* The foot's natural alterations under conditions of heat, humidity and moisture. For example, the average foot will increase about 5 percent in volume by the latter part of the day as compared with the early morning. On hot or humid days the foot expands more and it shrinks in cold temperature.

Key Reference:

Rossi WA & Tennant R: Professional Shoe Fitting. National Shoe Retailers Association. 1984 (this book is somewhat dated but is an excellent widely used source on footwear and footwear fitting).

	Characteristic	Review Definition
	Traction & Grip	This characteristic refers to the capacity of the boot to allow the dismounted soldier to minimize slippage and keep his/her feet whilst running, crawling and climbing by imbedding the tread on the outersole into a variety of terrain surfaces. This characteristic could be considered a subset of stability, but for the purposes of this Review was evaluated separately. **Key related characteristics:** Prevention of Injury, Safety, Flexibility, Comfort, Support, Stability, Durability and Health & Hygiene.
	Flexibility	The characteristic of ***flexibility*** refers to allowing the foot to function as close to its normal performance levels even whilst wearing the combat boot. Nowhere is this more important than in the forefoot at the "metatarsal break". If inadequate amounts of flexibility are available, excessive overload will occur from the plantar to the metatarsal heads of the foot causing pain and, furthermore, dramatically affect propulsion i.e., the ability of the soldier to freely walk, run, dodge and/or jump. **Key related characteristics:** Comfort, Support and Stability.
	Protection	The characteristic of ***protection*** is the combat boot's ability to protect the soldier's foot from specified man made threats. Whilst no one "safety standard" covers the in-service ADF combat boot, it must be constructed to provide a barrier for the soldier from any number of dangerous activities and circumstances he/she may face in an operational environment. This must be done within reason so as not to detract from the functionality of the boot. **Key related characteristics:** Comfort, Prevention of Injury, Environmental Protection, Health & Hygiene and Safety.
	Environmental Protection	The characteristic of ***environmental protection*** is the combat boot's ability to protect the soldier's foot from climatic and other non-climatic impediments. It is considered to be a fundamental problem if feet cannot be protected from the elements, particularly the ingress of water. Regardless of how the water gets into the boot, via stitching, vent holes or through the foot entry portal – problems will result. A complementary issue is the ability of moisture or sweat being unable to escape from the boot. Other non-climatic impediments such as sand and dirt are also problematic in certain environments. This characteristic could be considered a subset of protection, but for the purposes of this Review was evaluated separately. **Key related characteristics:** Comfort, Prevention of Injury, Protection, Foot Health & Hygiene, Durability and Safety.

	Characteristic	Review Definition
	Health & Hygiene	This characteristic refers to the combat boot's ability to allow the soldier to maintain a healthy and fit foot in operational environments. In combination with prevention of injury it encompasses the occupational health aspects of a combat boot. The minimisation of secondary health and hygiene problems on the foot, particularly of the skin, are paramount to a soldier's ability to function in the field. Many of these are related to heat, sweating, water ingress and the organisms that are propagated by these issues such as tinea, maceration of skin and blisters. Cold and chilling disorders are seen less frequently, particularly in hot tropical environment but they are of no less significance. **Key related characteristics:** Environmental Protection and Prevention of Injury.
	Comfort	Comfort is closely interrelated with Fit and other footwear characteristics. It is a subjective characteristic based on an individual's assessment on how the combat boot 'feels' during use in various environments. Such an assessment can change due to differing environmental factors e.g. a boot may feel 'comfortable' in a relatively benign environment, but becomes 'uncomfortable' in a more physically demanding environment. It is considered to be the most subjective, and arguably, after Fit, the next most important of all characteristics of the combat boot. **Key related characteristics:** Fit, Prevention of Injury, Stability, Support, Cushioning and Protection and Environmental Protection.
	Prevention of Injury	This characteristic refers to the combat boot's ability to prevent injury either from external factors or by the use of the combat boot itself not causing injury either short term or long term to the soldier. To prevent injury is a principal quality of any combat boot. **Key related characteristics:** Support, Stability, Traction & Grip, Protection, Environmental Protection, Health & Hygiene and Comfort.
	Safety	The characteristic of safety is the combat boot's ability to keep the soldier's foot from harm from specified hazards. Whilst no one "safety standard" covers the ADF military boot, it must be constructed to provide a barrier to the combat soldier from any number of dangerous activities and circumstances he/she may face in a non-operational environment. This must be done within reason so as not to detract from the functionality of the boot. This characteristic could be considered a subset of protection, but for the purposes of this Review was evaluated separately. **Key related characteristics:** Prevention of Injury, Traction & Grip and Protection.

	Characteristic	Review Definition
	Ease of donning / doffing	This characteristic refers to the ease with which the combat boot can be put on and removed by the soldier. An additional consideration could also be for boot removal following lower limb injury. A complicated process in a situation of providing immediate medical assistance to a foot injury could have deleterious effects on the soldier. **Key related characteristics:** Comfort, Health & Hygiene and Protection.
	Durability	This characteristic refers to the combat boot's ability to undergo reasonable 'wear and tear' by a soldier over a specified period. This could be further described in the following terms: "The combat boot continues to be fit for function under operational conditions for the dismounted soldier (essential X months, desirable XX months) and has a storage shelf life (Y years)." **Key related characteristics:** Comfort, Prevention of Injury, Support, Cushioning, Protection, Safety and Environmental Protection.

More detailed definitions of the characteristics adopted by the Review and related boot features are contained in Annex E to the Technical Report.

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ANNEX C

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ANNEX D

GLOSSARY OF TERMS

Throughout this report, the following terms have been used. Note that for brevity in this Executive Report, only the key terms are listed here - a more extensive listing of Abbreviations and Terms can be found at Annex C to the Technical Report.

Term	Description
Anti-static	Property providing reduced potential for the discharge of static electricity building up on the body which might cause fire or explosion.
Anthropometric	Measurements of the body or sections of the body.
Arches	The foot has a number of arch shapes formed by the bones, mainly the metatarsal arch, outer longitudinal and inner longitudinal.
Ball	In the foot, the ball comprises the heads of the five metatarsal bones and the surrounding tissue. On the shoe the ball is the corresponding section of area. Along with the heel, the ball is one of the two primary weight bearing and tread sections of the foot and shoe.
Biomechanics	The study of the human body and movement in mechanical terms.
Biomechanical Comfort	Term used to refer to collective biomechanical aspects of the boot such as; cushioning, shock absorbency, support, arch support, motion support, stability and flexibility.
Blister	A raised patch of skin filled with watery matter and caused by a burn or friction.
Dual Density	A shoe component with two different sections having different degrees of resilience or flexibility, such as sole and heel on a unit sole or a midsole and outsole, to meet the functional requirements of the foot.
Eyelets	A small, flat ring of metal or plastic attached to the upper along the eye stay to provide holes for the laces to pass through.
Flexion	The bend action of the foot across the ball, or of a shoe or outsole across the ball and vamp. The degree of the flex of the foot or the walking ease of the shoe.
Fit	The ability of the shoe to conform to the size, width, shape and proportions of the foot. Sizing that allows the proper fit and foot function inside the shoe.
Footbed	The area and shape of the shoe on which the foot directly rests; the insole and midsole.
Forefoot	The part of the foot from the ball or metatarsal heads forward.

Term	Description
Forefoot Flexion	The bending action of the forefoot.
Heel	The raised component under the rear of the shoe, consisting of any of a wide variety of shapes, heights, styles and materials.
Heel Cup (or Counter)	A cupped shaped insert to cradle the foot's heel for motion control or cushioning.
Hot Spots	A patch of skin on the foot subjected to friction causing discomfort and blisters.
Insole	A layer of material shaped to the bottom of the last and sandwiched between the outsole (or midsole) and the sole of the foot inside the shoe. It is the shoe's natural anchor to which is attached the upper, Toe box, linings and welting.
Insole Board	Material for an insole made of cellulose or other fibres imbedded with a matrix that binds the fibres close together. May be infused with antibacterial or antifungal additives. The board combines flexibility with stability.
Last	Used a noun, the plastic, wood or metal foot–shaped form over which the shoe is made to conform to the prescribed shape and size of the shoe. Used as a verb, it refers to the process of shaping the shoe to the last. The last is the single most important element in the shoe making process.
Lining	Inside covering of the shoe or boot, may be leather or fabrics incorporating features such a wicking, moisture control, antibacterial, odour control, e.g., vamp lining, and tongue lining.
Midsole	The layer of soling between outsole and insole. Used to provide a layer of cushioning.
Mondopoint	A system to designate the size of the last and/or shoe, which include a girth measurement and use a metric system. Designed by SATRA, its objective is to be an international shoe sizing system.
Orthopaedics	The medical specialty dealing with the diagnosis and treatment of anatomical deformities, lesions, injuries or diseases of the bones, joints, ligaments and muscles.
Orthotic	Any design or device, separate or inserted, or incorporated in the shoe for the accommodation, control, or correction of a foot or gait disorder, e.g. arch support.
Podiatry	The branch of medicine dealing with the diagnosis and treatment of foot disorders by surgical, mechanical or other means.
Shank	The bridge portion of the sole between the heel breast and the ball tread area.
Shin Splint	A tiny hairline fracture or surface damage to a bone, mainly a leg bone, when the tendon is pulled away from its attachment to the bone with consequent pain and inflammation.

Term	Description
Shock absorbency	The natural ability of a body part, such as the foot, to absorb a normal amount of shock as in walking or running; or the use of special shoe components or materials, such as cushioning, to aid in the absorption of step shock.
Size 270/94 (US 9–UK 8)	Mondopoint size length/width in mm (US–UK equivalent arithmetic sizes)
Sole	Derived from the Latin "solea", meaning soil or ground. Refers to the bottom part of the shoe in contact with the ground.
Sole Adhesion	The ability of the sole (or midsole) material to adhere to the upper of the shoe.
Step Shock	The jolt effect occurring with each step or stride when walking on a non–resilient surface with shoes lacking shock absorption.
Support	1. The foot's natural support system which includes the bones and joints, muscles and tendons, ligaments, arches, and plantar fascia. 2. Any supplementary components or design built into the shoe and offering support to the foot's own support system.
Toe Box (or Cap, or Toe Puff)	The firm, reinforced toe area of a shoe. Can be made from plastic, leather, fabric, fibreboard metal etc. To provide wear and/or impact protection.
Tongue	The flap part of the shoe's upper, or a section affixed to the vamp and extending rearward and upward to cover the instep or beyond.
Tongue Insert	Shape material inserted into the tongue pocket to provide padding to the instep.
Traction	The pulling or drawing of a load against the ground surface, and the leverage action resulting from the friction between the moving and the stationary part.
Tread	1. To walk on, or the particular way the weight bearing foot implants itself on the ground to create a tread pattern. 2. On the last, the widest section of the last bottom so that the shoe will "walk" properly. 3. On a shoe, the areas of the sole and heel that are in primarily contact with the ground in walking. Proper tread is important to the floor, last and shoe.
Upper	All the parts or sections (vamp, quarters, linings, etc) above the shoe's sole that are stitched or otherwise joined together to become a unit, and then attached to the insole and outsole.
Water Resistant	A material or product specially treated and designed to resist entry or repel absorption of moisture, but not necessarily waterproof.

Copy No: 2 of 2

Independent Review of the In-Service ADF Combat Boot: Technical Report Annexes

Defence Materiel Organisation

Melbourne
19th March 2008

Booz | Allen | Hamilton

Table of Contents

Annex A – Literature Review

Executive Summary

Introduction

The Booz Allen Review Team conducted an extensive search for existing literature covering footwear, military footwear, injuries related to military footwear, biomechanical impact of military footwear, load carriage in the military environment and the effects of cushioning on military footwear.

Annex Outline

1. Previous Reviews
2. Injury Reviews
3. Injury Prevention
4. Specific Aspects
5. References

Key Findings

Despite the long history of military footwear, dating back as far as 2700 years ago, there has been limited documented studies into their design, development and effect on soldiers. The literature review identified 31 articles of relevance to this Review.

The review of literature identified that it is not reasonable to design military footwear that covers all applications. Ultimately, the "design of military footwear encompasses not one but many compromises". As such, any design may "degrade the performance of the wearer" in some circumstances. The objective the designer of military footwear becomes a matter of identifying a solution that is acceptable in the most important roles of the soldier.

One study showed that the cushioning properties of army footwear was insufficient and resulted in increased risk of injuries. However, subsequent evidence from a review of seven trials assessing the use of shock absorbing insoles produced mixed findings on whether actual prevention of injury was achieved. One further study identified that only 2 out of 3 absorbing insoles were effective.

One study determined that using a boot with a softer shaft enabled a wider range of motion for the wearer and this would lead to more power generation.

Given the nature of military boots and their use, one study suggests that each kg of footwear is equivalent in energy cost to 5kg carried on the torso.

One study into the Canadian armed forces footwear found that only 58 of 825 soldiers had correctly fitted boots (length and width). An analysis of the ill fitting boots identified the key causes as availability of correct sizes, actual foot measurements not taken, feedback from wearer on "goodness of fit" not conducted, not specialist 'fit' advice sought and the soldiers themselves were not aware of what made a good fit.

Annex A – Literature Review

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The purpose of this brief overview is to summarise the available literature and military or combat footwear.

Soldiers have always used boots for the protection of their feet and legs. The earliest record of what could be considered combat footwear is apparently in a 2700 year old palace mural of Kin Sargon II – all the warriors are wearing snug fitting leather boots that are laced from knee to instep. Most appear to be colourfully decorated compared to the camouflage colours of today (Lawlor, 1996).

1.0 Previous Reviews

Two previous major reviews of military footwear have been identified in the literature. The first in 1984 by Howard and Oakley reviewed the experiences following the Falklands conflict. They noted that many of the longstanding problems that were associated with military footwear design remained unsolved and were highlighted during the conflict. They reviewed the functional requirements of the soldier in relations to the practical aspects of boot design. While this was in 1984, there have been substantial advances in materials available, manufacturing processes and civilian boot design. A large part of their review focused on the thermal issues due to the Falklands Island climate.

Their timely advice back in 1984 is very relevant to the current ADF combat boot review: *"Before governments pour large sums of money into equipping soldiers with the latest and most fashionable mountaineering boots, it is essential to decide what can be achieved, and how."* They also note that *"The design of military footwear encompasses not one but many compromises, almost all the ways of implementing the ideal requirements for a boot conflict with one another".*

The second major review was by Hamil and Bensel (1996) who carried out extensive material and biomechanical testing of military footwear to make recommendations for future iterations of boot design in the United States. They compared a range of footwear types (military, safety, running shoe) in terms of flexibility, stability, sole wear, water penetration, outsole friction, impact and weight. They then carried out a range of biomechanical tests (electromyographic; kinematic; kinetic; metabolic) while subjects walked on a treadmill. They noted that *"In the athletic shoe industry, manufacturers have not addressed the issue of producing a single footwear design for a multitude of applications. Instead, they have created specific shoes for specific purposes. Unlike the athletic shoes for the civilian market, a single design of military footwear must be used for a wide range of activities"* As a result of this, *"depending on the activity, the present military boot sometimes enhance and sometimes degrade the performance of the wearer, sometimes protect the wearer from injury and sometimes make the wearer more vulnerable to injury"*. The aim then becomes the design of a boot that is not 100%

satisfactory in every situation, but is above average acceptability in most of them. The authors made very specific recommendations for future design concern shock attenuation (better attenuation needed); inserts (more contoured and improved shock absorption); midsole construction and stiffness (more similar to a running shoe); medio-lateral stability (more stable); and upper construction (decreosed in height compared to current boots).

2.0 Injury Reviews

Lower limb injury rates high during initial military training and can lead to significant disability. Franklyn-Miller et al (2006) reported 18.6% of recruits being injured in the first 6 weeks. Yates and White (2004) reported almost 30% getting 'shin splints'. Bensel & Kish (1983) that 0.5% of males and 1.3% of female recruits were medically discharged because of foot or lower limb problems.

3.0 Injury Prevention

Given the high rate of reported injury in military recruits, the boot and insole have the potential to reduce injury rates. Seven trials have evaluated shock absorbing insoles for the prevention of injury:

- Schwellnus et al (1990) study in the South Africa armed forces with a sample size of 1511 found that neoprene insoles reduced incidence of overload injuries and stress fractures;
- Fauno et al (1993) found that a shock absorbing heel reduced the incidence of injury in soccer referees during a five day tournament;
- Withnall et al (2006) in a group of Royal Air Force recruits (UK) found no differences between three groups wearing a shock absorbing Poron insole, a shock absorbing Sorbothane insole and the standard non-shock absorbing insoles;
- Gardner et al (1988) found no difference stress fractures in United States marines in comparing the use of shock absorbing Sorbothane insole compared to the standard mesh insole;
- Andrish et al (1974) found no differences in the incidence between different conditians in a United States Navy population between a stretching and hell cushioning group;
- Sherman et al (1996) found no differences in lower limb injuries in a group of United States army recruits between a group wearing Spenco cushioning insoles and a no intervention group; and
- Hau et al (2000) showed a reduction in injury in those using more comfortable inserts in sample from the Candaian Army.

From a review of these studies, it appears that the results of trials to determine if increases in shock absorption can prevent injury are mixed.

4.0 Specific Aspects

Within running shoe research, the shoe is seen as a powerful tool to assist in performance and injury prevention. A significant amount of biomechanical

research has been carried out by independent academic research laboratories and published (Barnes & Smith, 1994), but also there is probably just as much done 'in-house' by running shoe companies. It is only recently that there has been renewed interest in the biomechanical effects of military footwear (eg Cikajlo & Matjacic, 2007; Hinz et al, 2007; Birrell et al, 2007). Two previous studies compared the military boot to a running shoe (deMoya, 1982; Hamil & Benael, 1996) and not surprisingly, found that the running shoe resulted in less impact forces. Harman et al (1999) compared two army boot, 5 prototypes army boots and 5 commercial hiking boots and were able to rank the boots from worst to best in a number of different performance categories. The purpose of this was to inform the decision making process for new military boot design. Williams et a (1997) looked at impact and biomechanical testing on a range of different configuratians of military footwear. They were able to identify optimal configuratians for different characteristics. The conclusion of these studies was the poor biomechanical characteristic of military footwear compared to running footwear and to highlight the lack of research and development af military footwear.

4.1 Boot Stiffness

Cikajlo & Matjacic (2007) looked at the effects that two different boots had on galt. The boots differed in their flexibility while and data was collected with and without carrying a backpack. The baot with a softer boot shaft enabled a wider range of mation in the ankle joint leading to more power generatian in the ankle joint during the push-off, increased step length and gait velocity. The stiffness of the boot did not affect knee or hip joint motion. The backpack mostly influenced the pelvis and trunk kinematics. They concluded that the assessment of boot stiffness in the stance phase can play an important role in the determination of footwear functional characteristics.

4.2 Pressure & Shock Absorption Distribution

The cushioning properties of army footwear have been identified as insufficient and related to a higher risk for injuries (Finestone et al, 1999). Metatarsal stress fractures (march fractures) account for 0.85% to 16% of injuries in recruits undergoing basic training and up to 31% in elite infantry units (Black, 1983). Hinz et al (2007) compared the pressure distributlon under the metatarsal heads in the boot used by the German armed forces with different insole designs. They compared the conventional synthetic mesh insole; a softer EVA foam and a neoprene rubber. Using pressure and force time integrals the neoprene rubber reduced the pressure and force to the lowest value. The reduction was greatest under the central metatarsals which are the more common site for stress fractures. The insoles used in the standard issue boot had a pressure distribution that wos highest under the central metatarsals.

Windle et al (1999) showed that shock absorbing insoles can reduce the peak pressures when running in military boots by up to 27% at the heel and 11% at the heel. In a subsequent study (House et al, 2002), they found that only 2 of 3 shock absorbing insoles were effective, so it can not be assumed that all

types of insoles can reduce peak forces. They further found that the insoles were still effective after degradation (Dixon et al 2003).

This highlighted significant room for improvement in the development of pressure and shock absorption and distribution. However, while there is room for improvement in the biomechanical lab based testing on shock absorption, there is somewhat of a paradox that previous field trials (3.0) have not necessarily shown a reduction in injury with improvements in shock absorption. The possible reason for that is probably related to the concept of the tuning of shock absorption to the individual based on muscle vibration frequency (Nigg, 2006).

4.3 Weight

Load carriage is an inevitable part of military life, both during training and on operations and can reach 100% of bodyweight in extreme circumstances, but is more likely to be 50-60% of bodyweight for shorter duration activities. The load is carried in a back pack and webbing. Weight influences mobility. Birrell et al (2007) investigated ground reaction forces in a number of conditions and showed that each 8kg increase in backpack load elicited an incremental increase in ground reaction forces. Importantly, they also investigated the effects of rifle carriage and found that this significantly increased the initial impact peak as well as the medio-lateral impulse. This may be due to changes in body sway and a restriction of the natural arm swing during rifle carriage. They speculate that these biomechanical effects of load carriage and rifle carriage may increase the risk for injury. The foot can adapt to heavy loads. Nyska et al (1997) looked at loading under the foot while carrying 20 and 40kg loads an a pressure platform. They showed that most of the increase in pressure and force was under the central and medial forefoot. There was no increase under the midfoot regions, suggested the longitudinal arch maintained its integrity. The key finding here was the influence that load and rifle carriage does influence lower limb biomechanics and need to be considered in military footwear design.

Miliatry boots are heavy and greater effort is needed to move a heavier boot. Each kg of footwear is equivalent in energy cost to 5kg carried on the torso (Goldman, 1981).

4.4 Fit

The correct fit of footwear is one of the key elements af footwear in being "fit for function". Dyck (2000) measured the foot size of 825 soldiers in the Canadian armed forces and reported that only 217 were wearing boots of correct width; 227 of the correct length and 58 wearing both correct width and length; clearly indicating that numerous soldiers were not being fitted correctly. They also noted that "soldiers admit that not enough effort expended to achieve a good fit, a deficiency that can be overcome with minimal training and patience".

Bailey (1989) identified five shortcomings in the process that led to poor fit in a military population:

1. There were insufficient sizes in the supply section;
2. No foot measurements were taken and this no comparisons made between foot sizes and boot sizes;
3. No feedback was sought from the wearer as to 'goodness of fit';
4. No confirmation of proper fit was made by a 'specialist'; and
5. There was insufficient knowledge by many wearers as to what actually constitutes a good fit.

References:

Andrish JT, Bergfield JA, Walheim J (1974): A prospective study on the management of shin splints. J Bone Joint Surg Am 56:1697-1700.

Bailey M & Hall RW (1989): Non gender safety footwear. Fit and Function Evaluation. Navy Clothing Research Facility . Jonuary 1989.

Barnes RA & Smith PD (1994): The role of footwear in minimizing lower limb injury. Journal of Sports Sciences 12:341-353.

Bensel CK & Kish RN (1983): Lower Extremity Disorders Among Men and Women in Army Basic Training and the effect of two types of boots. United States Army, NATRICK.

Birrell SA, Hooper Rh, Haslam RA: The effect of military load carriage on ground reaction forces. Gait and Posture (in press).

Black JR (1983). Stress fractures of the foot in male soldiers. A two year survey. Journal of the American Podiatry Association 73(12)633-4.

Cikajlo I, Matjacic Z (2007): The influence of boot stiffness on gait kinematics and kinetics during stance phase. Ergonomics. 2007 Sep 18;:1-12.

deMoya RG (1982): A biomechanical comparison of the running shoe and the combat boot. Military Medicine 147:380-383.

Dixon SJ, Waterworth CV, Smith S, and House SM (2003). Biomechanical Analysis of Running in Military Boots with New and Degraded Insoles. Med. Sci. Sports Exerc., Vol. 35, No. 3, pp. 472-479.

Dyck W (2000): A study of the relationship between foot size and combat boot in the Canadian Forces. Defence R & D. Canada.

Finestone A, Giladi M, Elad H et al (1999): Prevention of stress fractures using custom biomechanical shoe orthoses. Clinical Orthopedics and Related Research 360:182-90.

Fauno P, Kaland S, Anderson J, Jorgeson U (1993): Soreness in lower extremities and back is reduced by the use of shock absorbing heel inserts. International Journal of Sports Medicine 14:288-290.

Franklyn-Miller A, Boyington W, Steward I, Kilminster S (2006): Is Footscan predictive of lower limb injuries during initial military training? A pilot study. (unpublished).

Goldman RF (1981): Evaluating the effects of clothing on the wearer. In Cena, K & Clark JA (eds): Bioengineering, Thermal Physiology and Comfort. Elsevier Publishing.

Gardner LI Jr, Dziados JE, Jones BH, et al (1988). Prevention of lower extremity stress fractures: a controlled trial of a shock absorbent insole. Am J Pub Health; 78(12):1563-1567.

Hamill J & Bensel CK: Biomechanical Analysis of Military Boot (1996). Recommendation for the Design of Future Military Boots. Technicol Report. United States Army NATRICK.

Harman E et al (1999): A comparison of two army boots; 5 prototype military bootsand 5 commerical hiking boots - performance, efficiency and biomechonics. United States Army NATRICK.

Hinz P, Henningsen A, Matthes G, Jager B et al (2007) Analysis of pressure distribution belaw the metatarsals with different insoles in combat boots of the German Army for the prevention of march fractures. Gait and Posture (in press).

House CM, Waterworth, C Allsopp AJ, Dixon SJ (2002): The influence of simulated wear upon the ability of insole to reduce peak pressures during running when wearing military boot. Gait and Posture 1-7.

Howard E Oakley N (1984): The design and function of military footwear: a review following experiences in the South Atlantic. Ergonomic 27(6)631-637.

Lawlo L (1996): Where will this shoe take you. A walk through the history of footwear. Walker and Company. New York.

Nau A & Stefanyshyn D, Nigg B (2000): The effect of combat boot inserts on comfort, injury frequency and performance. Department of National Defence. Canada.

Nigg B (2006). Press Release. U of C kinesiologist says 'tuning' running shoes may be vital for injury prevention University of Calgary. Available at: http://www.ucalgary.ca/mp2003/news/feb06/nigg.html.

Schwellnus MP, Jordan G, Noakes TD (1990): Prevention of common injuries by the use of shock absorbing insoles. A prospective study. American Journal of Sports Medicine 18(6)636-41.

Sherman RA, Karstetter KW, May H, Woerman AL.(1996) Prevention of lower limb pain in soldiers using shock-absorbing orthotic inserts. J Am Podiatr Med Assoc; 86:117-122.

Williams KM et al (1997): Biomechonical Properties of Infantry Combat Boot Development. Naval Health Research Center. United States.

Windle CM, Gregory SM, Dixon SJ (1999): The shock attenuation characteristics of faur different insoles when worn in a military boot during running and marching. Gait and Posture 9:31-37.

Withnall R, Eastaugh J, Freemantle N (2006). Do shock absorbing insoles in recruits undertaking high level of physical activity reduce lower limb injury? A randomized controlled trial. J R Soc Med 99:32-37.

Yates B, White S (2004): The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. American Journal of Sports Medicine. 32(3)772-80.

Annex B – Foot Anatomy, Footwear and Fit

Executive Summary

Introduction
This Annex provides an overview of the basic understanding of foot structure and function, footwear structure, function and fit.
Annex Outline
1. Foot Anatomy 2. Foot Function 3. Footwear Anatomy 4. Footwear Function 5. Footwear Fit 6. Key Reference
Key Findings

Annex B - Foot Anatomy, Footwear and Fit

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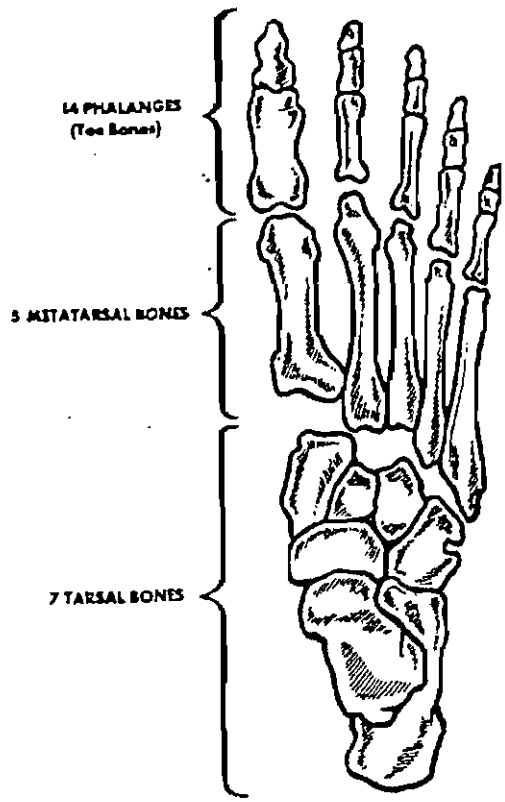
The purpose of this overview is to provide readers with a basic understanding of foot structure and function, footwear structure, function and fit.

Foot Anatomy

The human foot is a complex organ. Each foot consists of 26 bones (the 52 in both feet comprise 1/4 of all the bones in the body). Anatomically, the foot can be divided into the rearfoot (the tarsal bones, of which the calcaneus (heel bone) is the largest and bears the weight) and the forefoot. The forefoot consists of the five metatarsal bone and the phalanges (toes). There are two extra bones under the head of the first metatarsal called the sesamoid bones that function like mini knee caps.



Structurally, the foot consists of several arches and 38 joints. The longitudinal arch, which is higher along the medial (inside) than the lateral (outside), is considered the main arch. The transverse arch runs from the outside to inside in the midfoot (there is no arch across the metatarsal heads). The arches are responsible for a lot of the structural integrity of foot anatomy.

The foot is a complex structure, besides the bones the foot has 19 muscles and tendons, 18 of which are on the sole of the foot. There are 13 leg muscles whose extended tendons are attached to different places in the foot. There are 107 ligaments, far more than any other part of the body of equivalent size. The foot has about 60,000 sweat glands, 120,000 per pair, more thon found anywhere else on the body.

Anatomically, there are as many variations in foot anatomy as there are variations in the anatomy of the face. However, the foot with all these variations is expected to function on the same structure (usually a hard surface in footwear).

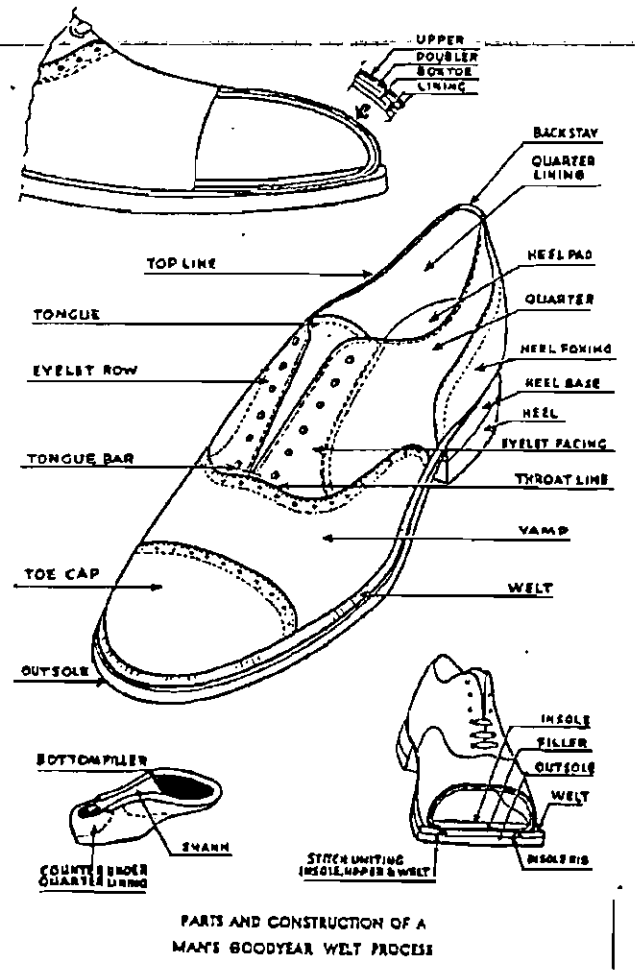
Foot Function

The foot serves a number of functions and carries out those functions as a masterpiece of engineering. During gait (walking), the heel contacts the ground first slight inverted (tipped out at the onkle). After the foot hits the ground it rolls inwards (pronates) to lower the longitudinal arch to help absorb shock and adapt to the terrain. If this pronation motion is excessive, it is considered pothologic. Also, at ground contact the knee and ankle bend to further help absorb shock. After this initial contact, the body moves forward over the foot at the ankle joint. Later in this stance phase, the heel begins to come off the ground; the rearfoot starts to roll outwards (supinate); and the foot bends at the metatarsophalangeal joints (across the ball of foot). All of this is to make the foot more efficient during propulsion.

Essentially at ground contact, the foot become a 'loose bag of bones' to absorb shock and adapt to the different underfoot surfaces; but then transforms into a 'rigid lever' during propulsion. Footwear has to, at least, not interfere with this process and, preferably, facilitate or enhance this process.

Footwear Anatomy

Footwear consists of a number of parts, with the two main parts being the upper and the sole. The upper consists of the quarter (the rear part); the vamp (the fore part); the heel seat (the area the heel sits on); the toe box (the 'roof' of the toe area); the counter (the firm part around the outside of the heel). The sole consists of the outsole (the port that contacts the ground); the insole or foot bed (the part that the foot rests on); the midsole (extra sole material between the outsole and insole). Also embedded in the sole is the shank to give the rear part of the shae some more stability. In addition to what has been traditionally called the insole or foot bed, there is often a removable insole or foot bed added for comfort. The terms used for these are commonly interchanges and may lead to confusion.



PARTS AND CONSTRUCTION OF A MAN'S GOODYEAR WELT PROCESS

There are many different technologies and methods of attaching the upper unit to the sole unit, such as stitchdown; goodyear weld; cement; slip lasted; and injection moulded. There are advantages and disadvantages of each method.

The materials used in all the different components are many and varied with each material having specific functional characteristics and their own advantages and disadvantages.

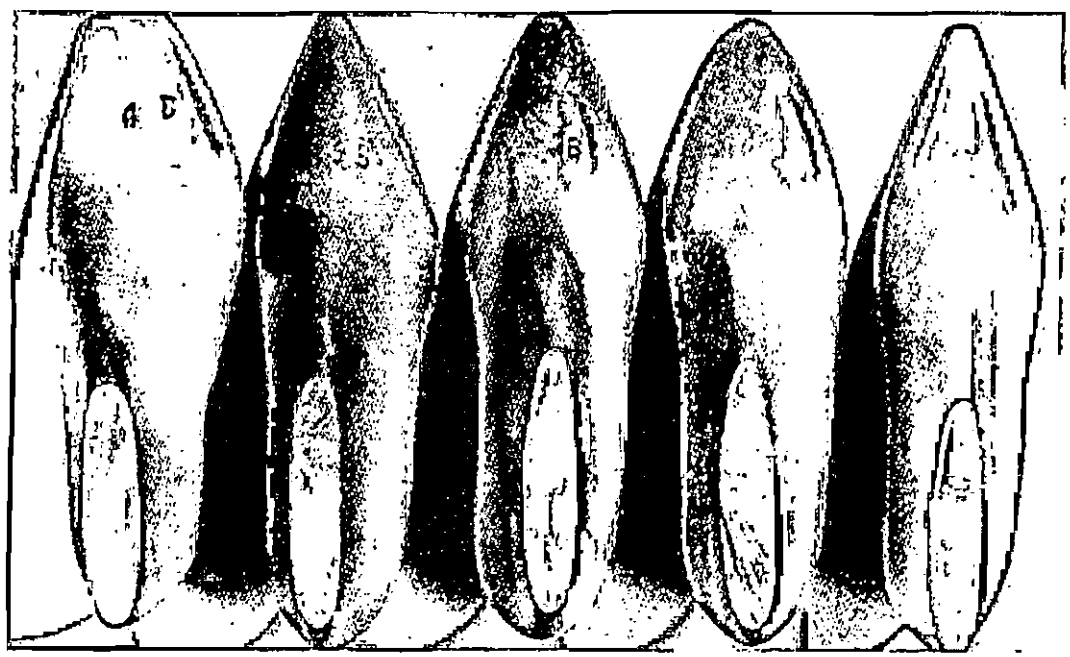
Footwear Function

As the foot is a complex structure that has to meet many demands and has many functions, so the footwear must not hinder and facilitate these functions (unless fashion dictates otherwise). The footwear must be stable where and when the foot is stable; yet the footwear must also be flexible when and where the foot is flexible. It has to achieve this in the context of many different environments and surfaces. And most of all it has to fit and be comfortable.

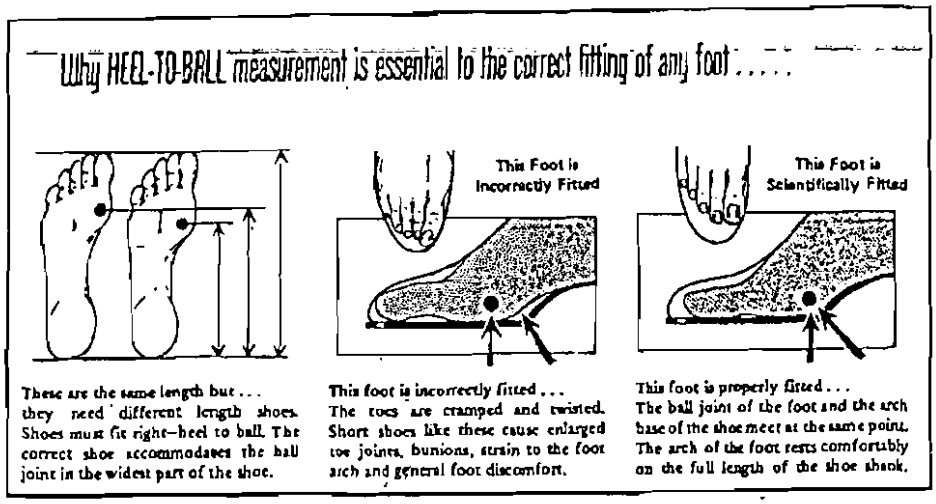
Footwear Fit

Fit is probably one of the most important considerations in footwear, yet is the one area that has no standard metric to measure it, due to the subjective nature of the concept of a good fit. The whole concept of fit is related to the three dimensional shape of the footwear (compared to the foot) and the particular characteristics of footwear function that any particular footwear has. Fit is the ability of the shoe to conform to the size, width, shape and proportions of the foot.

The central component of the three dimensional shape of footwear is the last. The last is the plastic (or wood) model that footwear is manufactured on. Each footwear size will have a different last, but all lasts for each footwear model will have the same ratio of measurements (i.e. the basic last shape). Each model of footwear and each manufacturer will generally have a different last shape that they consider provides the widest range of fit to the population that the footwear model is targeting.



During manufacture, the upper is stretched over the last and the insole board is attached to the upper to hold it in place; the outer sole is then attached (stitched or injection moulded) to this. The last is then removed.



Lasts have many measurements to characterise them (e.g. length, width, heel-to-ball, dorsal height, etc) as well as characteristics to assist with footwear function (e.g. heel height; toe spring, etc). All of these characteristics affect fit and function of the footwear to facilitate and hopefully enhance function of the foot.

There is no such thing as a "perfect" fit. It has been shown time and again that no person has two feet that are the same size, shape, proportions or functional character. In 1945, the US Army commissioned a study of foot measurements. 27 dimensions on both feet of 6,775 men were taken in a massive study. The most important conclusion: "...(to make a new single last to fit all men) may not prove possible since it is evident that consistent or orderly schemes of dimensional inter-relationships applicable to all, or even a majority of men, probably do not exist."

The foot is a dynamic structure and changes in size, shape and proportions. Fitting needs to account for the four phases of fit:

Static Fit: The foot at rest when the customer is seated.

Weight bearing Fit: The fit with the foot bearing weight, as in standing or loaded.

Functional Fit: Fit of the fit under dynamic conditions, such as walking, running, jumping etc.

Thermal Fit: The foot's natural alterations under conditions of heat, humidity and moisture. For example, the average foot will increase about 5 percent in volume by the latter part of the doy as compared with the early morning. On hot or humid days the foot expands more and it shrinks in cold temperature.

Key Reference:

Rossi WA & Tennant R: Professional Shoe Fitting. National Shoe Retailers Association. 1984 (this book is somewhat dated but is an excellent widely used source on footwear and footwear fitting).

Annex C – Glossary

Executive Summary

Introduction
This annex provides the Abbreviations and Glossary of Terms used in this report.
Annex Outline
1. Abbreviations 2. Glossary of Common Footwear
Key Findings

LASRA	Leather and Shoe Research Association Inc (NZ)
LTGEN	Lieutenant General
MINCS (L)	Minor Capital Submission (Land)
mm	Millimetre
NZ	New Zealand
OR	Other Rank
pH	pH is a measure of the acidity or alkalinity of a solution.
POL	Petroleum, Oils & Lubricants
PU	Polyurethane
QA	Quality Assurance
RAN	Royal Australian Navy
RAAF	Royal Australian Air Force
RAR	Royal Australian Regiment
R&D	Research and Development
RODUM	Report On Defective or Unsatisfactory Materiel
RTB	Recruit Training Battalion
SATRA	SATRA Technology Centre (UK)
UK	United Kingdom
US	United States
WGCDR	Wing Commander
3D	Three dimensional

Term	Description
	natural ease as the foot.
Flexion	The bend action of the foot across the ball, or of a shoe or outsole across the ball and vamp. The degree of the flex of the foot or the walking ease of the shoe.
Flex Line/Point	The line across the ball, bottom or top, on which the shoe bends or flexes in taking a step. Also known as toe break.
Fit	The ability of the shoe to conform to the size, width, shape and proportions of the foot. Sizing that allows the proper fit and foot function inside the shoe.
Footbed	The area and shape of the shoe on which the foot directly rests; the insole and midsole.
Foot Type –Pronator	A low arched foot.
Foot Type –Supinator	A high arched foot.
Foot Type – Neutral	A foot with a normal arch height.
Forefoot	The part of the foot from the ball or metatarsal heads forward.
Forefoot Flexion	The bending action of the forefoot.
Girth	Any of several circumference measurements taken on the last, such as around the ball, waist and instep; or similar measurements on the foot.
Goodyear Welt	A method of shoe construction. Distinguished by a raised insole rib to which both the welt and insole are sewn.
Ground Insulation	Protection against uneven ground surface "shadowing" provided by the sole and insole materials.
Heel	The raised component under the rear of the shoe, consisting of any of a wide variety of shapes, heights, styles and materials.
Heel Cup (or Counter)	A cupped shaped insert to cradle the foot's heel for motion control or cushioning.
Heel Height	The height, floor to shank, measured at the heel breast.
Heel Spring (or Camber)	The small space between the rear-bottom surface of the shoe heel and the floor. The heel spring is incorporated into the last to lessen heel strike impact, allow better step leverage and stability.
Heel (or Foot) Strike	The manner and impact force with which the heel of the foot and shoe strike the ground with each step or stride.
Hot Spots	A patch of skin on the foot subjected to friction causing discomfort and blisters.
Insole	A layer of material shaped to the bottom of the last and sandwiched between the outsole (or midsole) and the sole of the foot inside the shoe. It is the shoe's natural anchor to which is attached the upper. Toe

Term	Description
Shock absorbency	The natural ability of a body part, such as the foot, to absorb a normal amount of shock as in walking or running; or the use of special shoe components or materials, such as cushioning, to aid in the absorption of step shock.
Size Role (Range)	From smallest to largest sizes and width in a given footwear category.
Size 270/94 (US 9–UK 8)	Mondopoint size length/width in mm (US–UK equivalent arithmetic sizes)
Sole	Derived from the Latin "solea", meaning soil or ground. Refers to the bottom part of the shoe in contact with the ground.
Sole Adhesion	The ability of the sole (or midsole) material to adhere to the upper of the shoe.
Step Shock	The jolt effect occurring with each step or stride when walking on a non–resilient surface with shoes lacking shock absorption.
Support	1. The foot's natural support system which includes the bones and joints, muscles and tendons, ligaments, arches, and plantar fascia. 2. Any supplementary components or design built into the shoe and offering support to the foot's own support system.
Tanning	The complex chemical and mechanical process of converting raw hides and skins into leather by the use of tanning agents. The process involves an extensive series of operations.
Tarsus	The rear skeletal section of the foot composed of the seven tarsal bones.
Terry (cloth)	A fabric with uncut loops formed by the addition of an extra warp thread. Technique is used to provide padding and air space especially at pressure points in the sock.
Thermoregulation	The ability to control normal temperature.
Toe Box (or Cap)	The firm, reinforced toe area of a shoe. Can be made from plastic, leather, fabric, fibreboard metal etc. To provide wear and/or impact protection.
Toe Off	The push off from the shoes with the step.
Toe Puff	British term for a toe box.
Toe Spring	The elevation of the under surface of the sole at the toe to give the sole a slight rocker effect for an easier step.
Tongue	The flap part of the shoe's upper, or a section affixed to the vamp and extending rearward and upward to cover the instep or beyond.
Tongue Insert	Shape material inserted into the tongue pocket to provide padding to the instep.
Traction	The pulling or drawing of a load against the ground surface, and the

Term	Description
	leverage action resulting from the friction between the moving and the stationary part.
Tread	1. To walk on, or the particular way the weight bearing foot implants itself on the ground to create a tread pattern. 2. On the last, the widest section of the last bottom so that the shoe will "walk" properly. 3. On a shoe, the areas of the sole and heel that are in primarily contact with the ground in walking. Proper tread is important to the floor, last and shoe.
Upper	All the parts or sections (vamp, quarters, linings, etc) above the shoe's sole that are stitched or otherwise joined together to become a unit, and then attached to the insole and outsole.
Vamp	The lower forward part of the shoe's upper covering the forepart of the foot.
Waist	The section around the foot, last or shoe between the ball and instep.
Water Resistant	A material or product specially treated and designed to resist entry or repel absorption of moisture, but not necessarily waterproof.

Annex E – Functional Characteristics of the Combat Boot

Executive Summary

Introduction
The Booz Allen Review Team determined the key functional characteristics of a Combat boot and hence identified those parameters of a combat boot that make up the "Fitness for Function" criteria.
Annex Outline
1. Functional Characteristics of the Combat Boot 2. The Review Evaluation Methods Descriptions 3. Relative order of the Characteristics as assessed by the Review
Key Findings
The relative order of merit of the key functions of a combat boot are : 1 – Fit; 2 – Comfort, Support, Stability, Traction & Grip, Protection, Environmental Protection, Health & Hygiene, Prevention of Injury, Safety, Flexibility and Cushioning; and 3 – Ease of Donning & Doffing and Durability.

Annex E – Functional Characteristics of the Combat Boot

The Booz Allen Review Team determined the key functional characteristics of a Combat boot and hence identified those parameters of a combat boot that make up the "Fitness for Function" criteria.

	Characteristic	Review Definition	Relevant Boot Feature	Review Evaluation Method
	Fit	The characteristic of ***fit*** is the most important considerations of all footwear characteristics. Fit is the ability of the boot to conform to the size, width, shape and proportions of the foot. Fit is directly affected by the last but some other factors include: activity, psychology, style, materials and design. There is no way to measure fit and it has no clearly stated metric. Fit is achieved by trial and error and judged by "the soldier"; the manufacturer uses dimensional substitutes (length, width, etc). **Key related characteristics:** Comfort, Stability, Support, Flexibility, Safety, Health & Hygiene and Prevention of Injury.	Whole Boot, Sock	1. Qualitative Assessment 2. Quantitative Assessment (including anthropometric data modelling & analysis)
	Cushioning	The characteristic of ***cushioning*** is the inherent ability of the combat boot's components to individually, and/or collectively, dissipate the forces the foot and lower limb are exposed to during the stance phase of gait. The most critical time for this quality to be effective is during heel strike and toe–off when the soldier is involved in combat training, route marching etc. **Key related characteristics:** Fit, Stability, Prevention of Injury, Comfort, Support, Flexibility and Health & Hygiene.	Sole Unit, Insole, Footbed, Sock	1. Qualitative Assessment 2. Quantitative Assessment 3. Physical Testing
	Support	The characteristic of ***support*** is the ability of the combat boot to sustain the anatomical integrity of the foot when exposed to a level of intense activity that would normally not be undertaken unshod. The soldier would in turn feel safe and confident to re–attempt	Heel Counter, Footbed, Ankle Support, Midfoot Support, Whole Boot Fit, Forefoot Flexion,	1. Qualitative Assessment 2. Quantitative

	Characteristic	Review Definition	Relevant Boot Feature	Review Evaluation Method
		these activities repeatedly without fear of injuring him/herself. Minimising excessive lateral movement at the ankle and/or maintaining the position of the foot's medial arch under load would be examples of this quality. **Key related characteristics:** Fit, Comfort, Prevention of Injury, Safety, Flexibility, Stability and Health & Hygiene.	Arch Support, Sock, Heel Camber, Heel Height, Toe Spring,	Assessment
	Stability	The characteristic of ***stability*** refers to the capacity of the soldier to feel he/she has a level of steadiness or permanence whilst using the combat boot when undertaking intensive levels of activity. A feeling of confidence in a combat boot when in contact with the ground is critical for the dismounted soldier as it is an integral part of his/her proprioceptive (sensory) arsenal. **Key related characteristics:** Fit, Comfort, Support and Prevention of Injury.	Shank, Sole Rigidity, Upper Heel Counter, Weight, Whole Boot Fit	1.Qualitative Assessment 2. Quantitative Assessment 3. Physical Testing
	Traction & Grip	This characteristic refers to the capacity of the boot to allow the dismounted soldier to minimize slippage and keep his/her feet whilst running, crawling and climbing by imbedding the tread on the outersole into a variety of terrain surfaces. This characteristic could be considered a subset of stability, but for the purposes of this Review was evaluated separately. **Key related characteristics:** Prevention of Injury, Safety, Flexibility, Comfort, Support, Stability, Durability and Health & Hygiene.	Sole, Tread Design, Sole Grip	1. Qualitative Assessment 2. Quantitative Assessment 3. Physical Testing

	Characteristic	Review Definition	Relevant Boot-Feature	Review Evaluation Method
	Flexibility	The characteristic of ***flexibility*** refers to allowing the foot to function as close to its normal performance levels even whilst wearing the combat boot. Nowhere is this more important than in the forefoot at the "metatarsal break". If inadequate amounts of flexibility are available, excessive overload will occur from the plantar to the metatarsal heads of the foot causing pain and, furthermore, dramatically affect propulsion i.e., the ability of the soldier to freely walk, run, dodge and/or jump. **Key related characteristics:** Comfort, Support and Stability.	Forefoot Flexion, Sole & Upper Flexibility	1. Qualitative Assessment 2. Quantitative Assessment 3. Physical Testing
	Protection	The characteristic of ***protection*** is the combat boot's ability to protect the soldier's foot from specified man made threats. Whilst no one "safety standard" covers the in-service ADF combat boot, it must be constructed to provide a barrier for the soldier from any number of dangerous activities and circumstances he/she may face in an operational environment. This must be done within reason so as not to detract from the functionality of the boot. **Key related characteristics:** Comfort, Prevention of Injury, Environmental Protection, Health & Hygiene and Safety.	Toe Cap & Heel Cap (Impact) Sole & Footbed (penetration, rough surface, wear, cut, abrasion) Leather Upper, Anti-static Sole, Sole and Upper (environment, moisture, heat, cold, abrasion, cut, chemical)	1. Qualitative Assessment 2. Quantitative Assessment 3. Physical Testing
	Environmental Protection	The characteristic of ***environmental protection*** is the combat boot's ability to protect the soldier's foot from climatic and other non-climatic impediments. It is considered to be a fundamental problem if feet cannot be protected from the elements, particularly the ingress of water. Regardless of how the water gets into the boot, via stitching, vent	Sole & Upper Water Resistance, Dust/Sand Entry/Closure, Sock, Upper, Lining & Sole	1. Qualitative Assessment 2. Quantitative Assessment 3. Physical Testing

	Characteristic	Review Definition	Relevant Boot Feature	Review Evaluation Method
		holes or through the foot entry portal – problems will result. A complementary issue is the ability of moisture or sweat being unable to escape from the boot. Other non-climatic impediments such as sand and dirt are also problematic in certain environments. This characteristic could be considered a subset of protection, but for the purposes of this Review was evaluated separately. **Key related characteristics:** Comfort, Prevention of Injury, Protection, Foot Health & Hygiene, Durability and Safety.		
	Health & Hygiene	This characteristic refers to the combat boot's ability to allow the soldier to maintain a healthy and fit foot in operational environments. In combination with prevention of injury it encompasses the occupational health aspects of a combat boot. The minimisation of secondary health and hygiene problems on the foot, particularly of the skin, are paramount to a soldier's ability to function in the field. Many of these are related to heat, sweating, water ingress and the organisms that are propagated by these issues such as tinea, maceration of skin and blisters. Cold and chilling disorders are seen less frequently, particularly in hot tropical environment but they are of no less significance. **Key related characteristics:** Environmental Protection and Prevention of Injury.	Sweat Absorption. Moisture Transfer Lining, Water Resistance, Stitching Thermal Insulation/Transfer Anti-bacterial Protection, Sock, Whole Boot Fit	1. Qualitative Assessment 2. Quantitative Assessment
	Comfort	Comfort is closely interrelated with Fit and other footwear characteristics. It is a subjective characteristic based on an individual's assessment on how the combat boot 'feels' during use in various environments. Such an assessment can change due to differing environmental factors e.g. a boot may feel 'comfortable' in a relatively benign environment, but becomes 'uncomfortable' in a	Whole Boot Fit, Collar Height, Water Resistance, Moisture Control, Water Vapour Permeability, Support, Insulation, Weight	1. Qualitative Assessment 2. Quantitative Assessment 3. Physical Testing

	Characteristic	Review Definition	Relevant Boot Feature	Review Evaluation Method
		more physically demanding environment. It is considered to be the most subjective, and arguably, after Fit, the next most important of all characteristics of the combat boot. **Key related characteristics:** Fit, Prevention of Injury, Stability, Support, Cushioning and Protection and Environmental Protection.	Cushioning, Leather Quality, Toe Box Depth, Sock, Heel Camber, Heel Height, Toe Spring, Forefoot Flexion, Toe Cap	
	Prevention of Injury	This characteristic refers to the combat boot's ability to prevent injury either from external factors or by the use of the combat boot itself not causing injury either short term or long term to the soldier. To prevent injury is a principal quality of any combat boot. **Key related characteristics:** Support, Stability, Traction & Grip, Protection, Environmental Protection, Health & Hygiene and Comfort.	Whole Boot & Fit, Sole/upper, Weight, Toe Cap, Tread Design, Penetration Resistance	1. Qualitative Assessment 2. Quantitative Assessment 3. Physical Testing
	Safety	The characteristic of safety is the combat boot's ability to keep the soldier's foot from harm from specified hazards. Whilst no one "safety standard" covers the ADF military boot, it must be constructed to provide a barrier to the combat soldier from any number of dangerous activities and circumstances he/she may face in a non-operational environment. This must be done within reason so as not to detract from the functionality of the boot. This characteristic could be considered a subset of protection, but for the purposes of this Review was evaluated separately. **Key related characteristics:** Prevention of Injury, Traction & Grip and Protection.	Whole Boot & Fit, Grip, Traction, Penetration Resistance, Sole/Footbed Upper, Toe Cap & Heel Cap	1. Qualitative Assessment 2. Quantitative Assessment 3. Physical Testing
	Ease of donning / doffing	This characteristic refers to the ease with which the combat boot can be put on and removed by the soldier.	Lacing, Vamp Shape, Collar Height, Lace,	1. Qualitative Assessment

	Characteristic	Review Definition	Relevant Boot Feature	Review Evaluation Method
		An additional consideration could also be for boot removal following lower limb injury. A complicated process in a situation of providing immediate medical assistance to a foot injury could have deleterious effects on the soldier. **Key related characteristics:** Comfort, Health & Hygiene and Protection.	Tongue	2. Quantitative Assessment
	Durability	This characteristic refers to the combat boot's ability to undergo reasonable 'wear and tear' by a soldier over a specified period. This could be further described in the following terms: "The combat boot continues to be fit for purpose under operational conditions for the dismounted soldier (essential X months, desirable XX months) and has a storage shelf life (Y years)." **Key related characteristics:** Comfort, Prevention of Injury, Support, Cushioning, Protection, Safety and Environmental Protection.	X & XX – Outsole & Midsole (Wear, Cut Growth and Adhesion), Insole Wear, Stitching, Eyelets, Tread Leather, Heel Counter, Other Materials Y – Whole Boot	1. Qualitative Assessment 2. Quantitative Assessment 3. Physical Testing

The Review Evaluation Methods Descriptions:

1. Qualitative assessment. This form of assessment consisted of a number of qualitative approaches including Expert review with the Review Team, results from literature review, personal observations from user focus groups, and the results of interviews as part of stakeholder engagement.
2. Quantitative assessment. This form of assessment consisted of the following quantitative based approaches: analysis from survey data, test data and anthropometric data.
3. Physical testing. This form of assessment included both laboratory bench testing, biomechanical trial and physical examination of the combat boot.

Relative order of the Characteristics as assessed by the Review

No 1. Fit.

No 2. Comfort, Support, Stability, Traction & Grip, Protection, Environmental Protection, Health & Hygiene, Prevention of Injury, Safety, Flexibility and Cushioning.

No 3. Ease of Donning & Doffing and Durability.

Annex G – Stakeholder Engagement

Executive Summary

Introduction
The Booz Allen Review Team conducted a wide ranging series of stakeholder engagements as part of this review. The stakeholder engagements included Defence, other Government specialists and Footwear Industry manufacturers and experts. This Annex details those engagements.
Annex Outline
1. Stakeholder Engagement 2. Notes
Key Findings

Annex G – Stakeholder Engagement

The Booz Allen Review Team conducted a wide ranging series of stakeholder engagements as part of this review. The stakeholder engagements included Defence, other Government specialists and Footwear Industry manufacturers and experts. This annex details those engagements.

Date	Organisation Name	Organisation Type	Location
16/07/07	Vic Labs	Industry – Test	Melbourne
19/07/07	DSTO	Defence – Research and Development	Melbourne
20/07/07	Shoemate Pty Ltd	Industry – Manufacturer	Melbourne
07/08/07	RAN	Defence – potential user	Canberra
08/08/07	RAN	Defence – potential user	Canberra
14/08/07	RAAF	Defence – potential user	Canberra
27/07/07	Redback	Industry – Manufacturer	Melbourne
27/07/07	Army	Defence	Canberra

Date	Organisation Name	Organisation Type	Location
30/07/07	CSIRO	Government – Research and Development	Melbourne
01/08/07	Redback	Industry – Manufacturer	Sydney
03/08/07	Oliver	Industry – Manufacturer	Ballarat
13/08/07	Army	Defence	Holsworthy
13/08/07	Abar Rubber	Industry – Supplier	Melbourne
13/08/07	Normac Trading Pty Ltd	Industry – Supplier	Melbourne
14/08/07	Army	Defence	Singleton
16/08/07	Army	Defence	Townsville
21/08/07	Packer Leather Pty Ltd	Industry – Supplier	Melbourne
24/08/07	Shoemaster	Industry – Supplier	Melbourne
28/08/07	Army	Defence	Puckapunyal
29/08/07	Asics	Industry – Manufacturer (sports	Melbourne

Date	Organisation Name	Organisation Type	Location
		footwear)	
29/08/07	Redback	Industry – Manufacturer	Melbourne
30/08/07	NZ Leather and Shoe Research Association (LASRA)	Industry – Testing, Research and Development	Palmerston North, NZ
04/09/07	Taipan Footwear	Industry – Manufacturer	Melbourne
10/09/07	DSTO	Defence – Research and Development	Melbourne
12/09/07	Blundstone Footwear	Industry – Manufacturer	Hobart
12/09/07	Crossfire	Industry – Manufacturer	Braidwood
13/09/07	Top Socks	Industry – Manufacturer	Melbourne
13/09/07	AUSPAC Textiles	Industry – Manufacturer	Melbourne
13/09/07	Capogreco	Industry –	Melbourne

Date	Organisation Name	Organisation Type	Location
	Fashions	Manufacturer	
14/09/07	Oliver Footwear	Industry – Manufacturer	Ballarat
19/09/07	CSIRO	Government – Research and Development	Melbourne
24/09/07	CSIRO	Government – Research and Development	Melbourne
25/09/07	Crossfire	Industry – Manufacturer	Melbourne
26/09/07	Astley Leathers (NZ)	Industry – Manufacturer	Auckland
03/10/07	CLO SPO	Defence	Melbourne
03/10/07	CLO SPO	Defence	Melbourne
08/10/07	Army	Defence	Puckapunyal
08/10/07	DVA	Gov't	Melbourne
09/10/07	CSIRO	Government – Research and Development	Melbourne

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Date	Organisation Name	Organisation Type	Location
09/10/07	CLO SPO	Defence	Melbourne
09/10/07	DOHS	Defence	Melbourne
15/10/07	Army	Defence	Kapooka

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Annex V – Industry Responses

Executive Summary

Introduction
The Booz Allen Review Team conducted a series of stakeholder engagements as part of this review. One key component of this process was to engage a broad section of the footwear industry. Five Australian footwear manufacturing companies responded in writing to the Booz Allen Review. These include: Crossfire,
Annex Outline
1. Industry Responses 2. Appendices
Key Findings

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Annex V – Industry Responses

CRITERIA	Crossfire (as shown in Appendix 1)
Criteria 3: Advise whether the boots meet current manufacturing standards.	NO. Whose standards? US. UK, Canadian?
Criteria 4: Advise whether the boot has any inherent orthopaedic issues.	Yes. Approximately 2000 soldiers have called Crossfire regarding their injuries. • Paddle Foot last; • Lack of proper rocker; • Steel shank concentrates shock and stress under the foot; • DDR walls break down allowing upper to slump. This changes size and exacerbates pronation and causes loss of torsion stability; • Un–stabilised midsole permits structural collapse allowing the boot to slump; • Heat and water issues keep foot skin damp, soft and prone to blisters; • Silly sizing system which confuses issuing staff; • Un–stabilised heel counter; and • Inconsistent shock absorption.
Criteria 5: Advise on the appropriateness and critical need for the identified fitment and	• There is no fitment and maintenance regime; and • Mondo Point size chart

SQ 3

CRITERIA	Crossfire (as shown in Appendix 1)
maintenance regimes.	guarantees total confusion and greatly increases chances of wrong size being issued.
Criteria 6: Assess whether the boot requires any structural improvements.	It is not possible to improve the Terra boot. The DDR production process cannot deliver structural integrity of the level required by Combat.
Criteria 7: Advise whether the boot could be improved through non-structural minor	No it can't be. The "iterative" process has been tenet DMO boot design up until recently. Minor tweaks have

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CRITERIA	Crossfire (as shown in Appendix 1)
improvements.	failed to redeem a flawed basic concept.
Is it possible to achieve a range of combat boot sizes and widths to allow a fit of at least 95% of the male and female adult population?	No. As evidenced by the number of soldiers who are instructed to call Crossfire for proper fitting boot. Yes with properly designed Goodyear welt boots.
Is it possible to achieve a range of sizes and widths to allow a fit of 99% of the male and female population?	As above for 99% military population.
Is there a recommended lacing pattern that provides optimum support?	Lacing pattern makes no difference to performance of Terra boot. Extra tension on laces just promotes more side wall breakdown and slumping.

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CRITERIA	Crossfire (as shown in Appendix 1)
Other Observations	The DEF(AUST) 8547 must inevitably result in an unstable, sweaty, orthopaedically damaging, ill fitting and short lived basic work boot.

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Crossfire

24th September 2007

Mr Steven Holloway
Booz Allen Hamilton
Level 53
101 Collins St
Melbourne
VIC 3000

Dear Steve,

Thanks for the chance to comment to ADF Combat Boot Review.

I note you have sent a draft – DEF (AUST) 8547 / Draft A May 2007. This is not the spec to which any Terra I've seen has been made.

I will also comment to Army (AUST) 6743 August 2004, which covers most current issue boots.

To your points:

a (1) "Criteria 3. Advise whether the boots meet current manufacturing standards."

Whose standards? US, UK, NATO, Canadian standards? Answer is no. No other first world army uses a boot remotely similar.

(2) "Criteria 4. Advise whether the boot has any inherent orthopaedic issues".

Yes it does, as constantly told us by injured soldiers. Approximately 2,000 in last three years have called us.

- Paddle foot last. Not known on any other military boot in the world.
- Lack of proper rocker.
- Steel shank concentrates shock and stress under fore foot. Mine hazard (the ultimate orthopaedic failure).
- DDR walls break down allowing upper to slump. This changes size, exacerbates pronation and causes loss of torsional stability.
- Unstabilised midsole permits structural collapse, allowing the boot to slump out of corrective fit. Even if it fits in the Q store it won't fit after a few weeks of wear.
- Heat and water issues keep foot skin damp, soft and prone to blisters.

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PO Box 94, Braidwood NSW 2622, Australia ◆ Phone: +61 2 4842 2677 Fax: +61 2 4842 2950
Email: info@crossfire.com.au

- Silly sizing system which confuses issuing staff.
- Unstabilised heel counter breaks sideways and allows pronation and skeletal misalignment.
- Inconsistent shock absorption underfoot.

b (1) "Criteria 5. Advise on the appropriateness and critical need for the identified fitment and maintenance regimes".

What does this mean? There is no "fitment and maintenance regime' in DEF (AUST). Soldiers consistently report there are no trained fitting personnel at issue points. This was promised in Army News in 2003 but does not seem to have happened.

DEF (AUST) does however, include a Mondo Point (Italian Ski boot sizing system) size chart which guarantees total confusion and greatly increases chances of wrong size being issued.

(2) "Criteria 6. Assess whether the boot requires any structural improvements."

It is not possible to improve the Terra. The DDR production process cannot deliver structural integrity of the level required by Combat.

(3) "Criteria 7. Advise whether the boot could be improved through non-structural minor improvements".

No it can't be. The "iterative" improvement process has been tenet of DMO boot design up until recently. Minor tweaks have failed to redeem a flawed basic concept.

c (1) "Is it possible to achieve a range of combat boot sizes and widths to allow a fit of at least 95% of the male and female adult population".

This question should read: "...military population".

If so, the answer is no, with Terra. As evidenced by the number of soldiers who are instructed to call CrossFire for proper fitting boot.

The answer is yes, with properly designed Goodyear welt boots.

(2) As above for 99% military population.

(3) "Is there a recommended lacing pattern that provides optimum support".

Lacing pattern makes no difference to performance of Terra boot. Extra tension on laces just promotes more side wall breakdown and slumping.

I'm surprised by the very narrow range and ambiguity of questions asked. I realise that is your clients wording not BAH. As you have sent a copy of latest DEF (AUST) I'll make a few comments on it.

Clause 2.2.2

ARMY (AUST) DPD 8430-2002. Here is the heart of the problem. Army are providing tooling which forces suppliers to use a substandard construction technology.

2.2.3

ARMY (AUST) 6551. Obliges manufacturer to use a completely outdated shank material which creates all sorts of biomechanical and durability problems.

3.1.1

Mandates vulcanised or injected DDR construction technique. Automatically excludes quality Goodyear Welt construction.

Mandates circulation of air, which Terra doesn't do.

3.2.4

Side Panels. Mandates Kangaroo leather. Most Terra we have seen use completely non breathable PU coated nylon.

3.2.5

Steel Shank. Totally inappropriate material in a Combat Boot. Useful for cavalry to take stirrups.

3.2.7

Vamp lining mandates "hydrophilic layer". This shows complete lack of understanding of modern fabric technology.

3.2.8

Insoles. There is no mention anywhere of a structural midsole.

3.2.10

There is no mention anywhere of stabilising the heel counter into the boot structure.

3.2.11

"Hydrophilic" again.

3.2.12

Toe Puff. No mention of stabilising the toe puff into the boot structure.

3.2.16.1

Why? This spec precludes use of proper shock absorbing materials.

3.2.16.2

No reference to durameter, non-slip, heat resistance, POL resistance?

3.2.17.1

Universally disliked item except for amphibious operations (who don't use the Terra anyway as paddle foot last won't work with flippers.)

3.2.17.2

Poor spec.

3.2.17.3

Why?

3.2.17.4

Why?

3.3.1

This is the crucial point. Quality manufacturers would not use such knives, moulds and lasts. If they did that to supply their other markets they'd be out of business in short order.

3.4.3

Confusion enhancing Clause.

SUMMARY

Following DEF (AUST) 8547 must inevitably result in an unstable, sweaty, orthopaedically damaging, ill fitting and short lived basic work boot.

A great way to get your beers paid for at an O.S. military trade show is to plunk a pair of Terras on the bar. When footwear experts have stopped laughing they'll buy you drinks out of sympathy for any poor schmuck who has to wear them. Most refuse to believe that a major service would inflict such destructive footwear on their troops. I am ashamed to have to tell them that ADF does.

Hope these comments are of some use to you.

Yours sincerely,

Peter Marshall.

Annex AA – Foot Scanning Technology

Executive Summary

Introduction
The correct fitment of the boot to the soldier is a critical component to help ensuring that the boot can achieve "Fitness for Function" for each wearer. As part of this study, the Booz Allen Review Team reviewed existing foot measuring equipment and their alternatives.
Annex Outline
1. Measuring by Hand 2. Photo Imagery 3. 3D Scanning
Key Findings
The review team noted that three primary measuring techniques exist for foot measurements. In order of lowest accuracy and least cost, these are: measuring by hand (current system), measuring by photo imagery and measuring by 3D scanning.

Annex AA – Foot Measuring Equipment and Alternatives

There are a variety of methods of measuring the foot for the purposes of shoe or boot fitment and for custom-made footwear. Some common methods available include measurements by hand, photo imagery and 3D scanning. These notes provide a summary on each.

1. **Measuring by Hand:** This can be done by way of using a tape measure and size (Ritz) stick. Historically, this is how all feet were measured 20 – 30 years ago. This was improved by the introduction of the Brannock measuring system shown in Figure 1. The Brannock device measures for overall length, heel-to-ball, and ball width. While practical, it will only be beneficial if all measurements are utilized.

   A modified Brannock system was developed for use , also shown in Figure 1. Within this system, the foot is placed on the device and the length and width are measured; this determines the size and width. This is merely a guide and necessitates a smaller and larger size to be tried on to determine the best fit. While measurement by hand is widely used, it only actually gives the user 2 dimensional information i.e. foot length and width. There is no facility in this system of acquiring circumferential measurements.

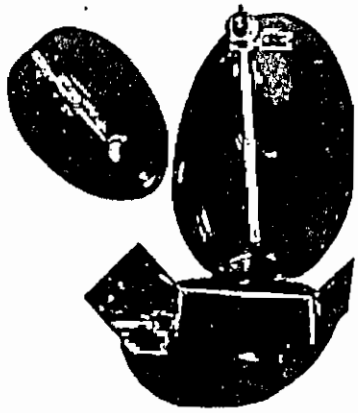
Figure 1 – Brannock and ADF Measuring Instruments

Brannock

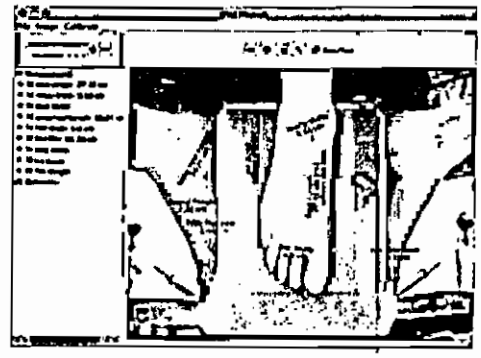
ADF Measurement System

2. **Photo Imagery:** Photo Imagery involves using captured images, which can then be measured to gather the dimensions of the foot (see Figure 2 below). One commercial system of measurement system is known as ePod – Essential Point of Difference. ePod was developed in Australia as a cost effective and portable way of measuring the foot. ePod has a tolerance of 2 mm and can be used to size the foot. ePod can also be developed to match the foot to a last or recommend whether a custom last be made. ePod gives an image of the foot, which can be used by a Podiatrist or other health professionals in determining if an Orthotic consultation maybe necessary. This is used in a medical custom footwear company that uses ePod to make custom medical footwear.

Figure 2 – ePod Measurement Device and Image



ePod Device

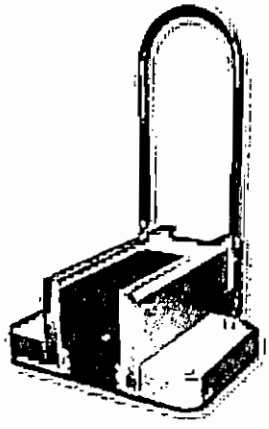


ePod Measurements

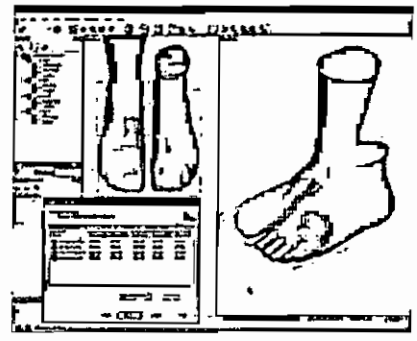
3. **3D Scanning.** 3D scanning is the most accurate way of acquiring measurements and dimensions of the foot. 540

. 3D Scanning uses a laser light to capture the foot data at 1mm increments (see Figure 3). The data is configured by a number of different software packages. Once the data has been imported into the computer software, it can be matched to the best fitting last. Furthermore, the software can also specify if a custom last is needed and the captured data can be emailed direct to the boot manufacturer. Data captured by such devices provides an invaluable source of information for developing lasts and size roles.

Figure 3 – 3D Measurement Device and Data Collection



3D Scanner



3D Measurements