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THE DEVELOPMENT OF AN AUTOMATIC MULTI CALIBRE WEAPON SYSTEM BY MEANS OF SIMULATION AND TESTING

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I present this Thesis as a symbol of appreciation to my wife Hester and our children Mariska, Pieter and Carike for their encouragement throughout the development of the GAMA.

ABSTRACT

This thesis describes the development of GAMA, (Gun Automatic Multiple Ammunition), a unique, multi calibre, rapid firing weapon with the aid of simulation and testing. Simulation at the time did not fully support the contemporary sophisticated tool sets, and therefore a method was designed to use simulation and experimental development interactively. Simulation models were generated modularly whilst phasing it with the acquirement of experimental test data.

Successes in the cross correlation of results progressively supported simulation over the extensive use of testing experimental hardware. Nevertheless, the knowledgeable use of simulation combined with experimental processes supported the practice of calibrating models before use. This prevented time wastage since unnecessary detail did not need to be simulated.

Authenticated base line models provided an accredited tool throughout the development of GAMA.

Using simulation judiciously and interactively with testing resulted in a foundation for the expansion of GAMA, thus optimising its performance and reliability whilst reducing time and cost.

The uniqueness in this project consists of the fact that no similar, multi-calibre gun has existed in the world at the time, nor does it exist today. In addition, many of the simulation techniques used were novel and specifically designed for this project against the background of the world-wide arms embargo against South Africa.

OPSOMMING

Hierdie tesis beskrywe die ontwikkeling en toetsing van GAMA, ("Gun Automatic Multiple Ammunition") 'n veeldoelige kaliber snelvuur wapen d.m.v. die gebruik van simulasie en toetsing. Destydse simulasie sagteware het nie oor al die hedendaagse gesofistikeerde hulpmiddels beskik nie en dienooreenkomstige beperkings op die gebied het die ontwikkelingsvermoë aan bande gelê.

Ontwikkeling van hierdie wapen is bewerkstellig deur die interaktiewe gebruik van simulasie en toetsing. Die skepping van simulasie modelle was modulêr gestruktureer waarvan elke module 'n sekere fase in die wapen se vuursiklus verteenwoordig het. Die modelle is deurentyd vergelyk met die eksperimentele data wat verkry is.

Die wedersydse gebruik, en die kruis korrelasie tussen, simulasie en toets data het gelei tot die spoedige ontwikkeling en die sukses van GAMA. Die oordeelkundige gebruik van simulasie modelle het dus verseker dat tyd nie verkwis is deur die modellering van onbenullige detail nie. Dit het derhalwe verseker dat detail wat geen bydrae gelewer het tot die ontwikkeling van die wapen nie, gereduseer sou word tot meetbare fenomene waarteen die modelle gekalibreer is. Dit is bekend dat die implementering van detail en die gebruik van komplekse randvoorwaardes die beheer van 'n model onnodig kan bemoeilik.

Hierdie geakkrediteerde modelle was die fondasie waarop die ontwikkeling van GAMA berus het. Dit is ook die grondlegger tot die verdere ontwikkeling en die uitbreiding van GAMA, waarmee die modifikasie en optimalisering van die wapen effektief en maklik geëvalueer kan word.

Die uniekheid van hierdie tesis lê daarin dat ten tye van die projek geen soortgelyke multi-kaliber wapen bestaan het nie, en trouens nog steeds nie elders in die wêreld bestaan nie. Ook moes baie van die tegnieke en

simulasiemodelle ontwikkel word teen die agtergrond van die algehele wapenverbod teen Suid-Afrika, wat enersyds tegnologiese ontwikkeling gestrem het, maar andersyds innovasie aangemoedig het.

PREFACE

Armament is a commodity that provides its owner with the ability to secure its boundaries, properties and lives, against threats. The competitive drive in the armaments industry resulted in the development of a superior product for the South African National Defence Force (SANDF), which provided the security forces with a product able to compete with the best in the world. At the same time, the processes used, demonstrated that the local industry can be rated to be on the leading edge of technology.

Vektor was approached to develop a Multi Calibre Rapid Firing Gun, addressing the need to the firing of 20x102 mm ammunition. The primary focus was to develop a weapon capable of firing a range of ammunition which would be fitted to the South African Air-Force (SAAF) new Light Utility Helicopter (LUH). The secondary purpose resided in the marketing of such a product internationally.

Such a weapon would provide the SANDF LUH with the capability of being deployed anywhere in the world for peacekeeping purposes, enabling the firing of foreign ammunition without intensive use of logistical support.

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NOMENCLATURE

3D	Three Dimensional
ABL	Allocated Base Line
ADM	Advanced Development Model
AGL	Automatic Grenade Launcher
AMS	Aerospace Monitoring & Systems (Pty) Ltd.
AP	Armour Piercing
ARMSCOR	Armament Corporation of South Africa - Procurement Division of the SANDF
A-Spec	System / Segment Specification
B-Spec	Development Specification
CAD	Computer Aided Design
CAR	Corrective Action Request
CDR	Critical Design Review
CFE	Client Furnish Equipment
CM	Configuration Management
CME	Cape Manufacturing Engineering Pty Ltd
CNC	Central Navigation Computer
COC	Certificate of Conformance
COG	Centre of Gravity
CPU	Central Processing Unit
CSIR	Council for Industrial and Scientific Research
C-Spec	Product Specification
DC	Direct Current
DEXSA	Defence Exhibition South Africa
DLS L	Denel Land Systems Lyttelton - A Division of Denel
DOD	Department of Defence
D-Spec	Process Specification
ECP	Engineering Change Proposal
EDM	Engineering Development Model
E-Spec	Material Specification
ESR	Electro Slag Re-melting / Refining
FBL	Fuctional Base Line
FCA	Functional Configuration Audit
FEA	Finite Element Analysis
FLTR	From Left to Right
FMECA	Failure Mode, Effect and Critical Analysis
FQR	Formal Qualification Review
FRACAS	Failure Review Analysis and Corrective Action System
FRP	Full Rate Production
GA1	Gun Aircraft No. 1
GAMA	Gun Automatic Multiple Ammunition
GI2	Gun Infantry No. 2
HEI	High Explosive Incendiary
HEIT	High Explosive Incendiary with Tracer
HP	High Pressure
ILSP	Integrated Logistic Support Plan
kg	Kilograms

LASER	Light Amplification by Stimulated Emission Radiation
LBL	Logistical Base Line
LIW	Armament Developer (Large Calibre) - A Division of Denel
LOR	Level of Repair
LRIP	Low Rate Initial Production
LSAP	Logistic Support Analysis Plan
LSAR	Logistical Support Analysis Record
LUH	Light Utility Helicopter
LVDT	Linear Voltage Differential Transducer
m/s	Meters per Second
MA	Motion Analysis
Mb	Bending Moment
MBL	Manufacturing Base Line
Mbx	Bending Moment Direction X
Mby	Bending Moment Direction Y
Md	Torque
MEC	Main Equipment Code
MG	Maschinen Gewehr (Machine Gun)
MK	Maschinen Kanon
MPI	Mean Point of Impact
MRI	Master Record Index
NATO	North Atlantic Treaty Organization
NDT	Non Destructive Testing
NTS	Not to Scale
OBL	Operating Base Line
ORS	Operational Requirement Statement
OSBL	Operational Support Base Line
OWS	Overhead Weapon System
P	Normal Force
PBL	Product Base Line
PCA	Physical Configuration Audit
PDR	Prelimanary Design Review
PMP	Pretoria Metal Pressings (Ammunition Manufacturer) - A Division of Denel
PPM	Pre-Production Model
PRR	Production Readiness Review
RBL	Requirement Base Line
Rds	Rounds
RFP	Request for Proposal
ROC	Requirement Operation Capability
ROGUE	Remotely Operated Gun and Observation System
RSA	Republic of South Africa
SAAF	South African Air Force
SANDF	South African National Defence Force
SAPHEI	Semi-Armour Piercing High Explosive Incendiary
SDR	System Design Review
SE	Systems Engineering
SEMP	System Engineering Management PLan
SK002	"Spesiale Kwaliteit 002" according to USCO Code

SRR	System Rediness Review
STR	System Technical Review
t	Temperature
TEMP	Test and Evaluation Master Plan
TP	Target Pratice
TPT	Target Practice with Tracer
URS	User Requirement Statement
USCO	Union Steel Company *now known as* " MITTAL Steel Association"
V	Volts
Vektor	Armament Developer (Small to Medium Calibre - A Division of Denel
XDM	Experimental Development Model
ϵ	Strain

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CHAPTER 1 INTRODUCTION

1.1 Background

Often a request is received for a weapon system capable of firing foreign ammunition which is calibre related. Ammunition usage greatly depends on the scenario for which the weapon is to be utilized. Typically, when a request for a weapon system does not match the current inventory, one of the following actions is taken by the weapons supplier:

a) Since the client's needs do not match the product line, the request is rejected.
b) The customer is persuaded to use an alternative weapon system within existing inventory.
c) A new weapon system is designed that will address the customer's specific needs.

Options "b and c" would be preferable for overall business strategy. However, related issues such as cost and time frame together, with the complexity of the request, have to be addressed whenever a new weapon system is developed.

Traditionally, development relies on the Standard Systems Engineering approach for the development of new products, and this by its very nature can be a time consuming process. This process is clearly defined as a work instruction. [001] Such an approach guides the project through all its development phases, forming a part of the total life cycle of the system. Each phase has its unique requirement with built in checks, reducing the risk of failure.

During the initiation phase the client's User Requirement Statement (URS) or Operational Requirement Statement (ORS) and Request for Proposal (RFP), calls for the preparation of specifications for which all the answers are not

yet known. The life cycle of any system is schematically summarized in Figure 1.

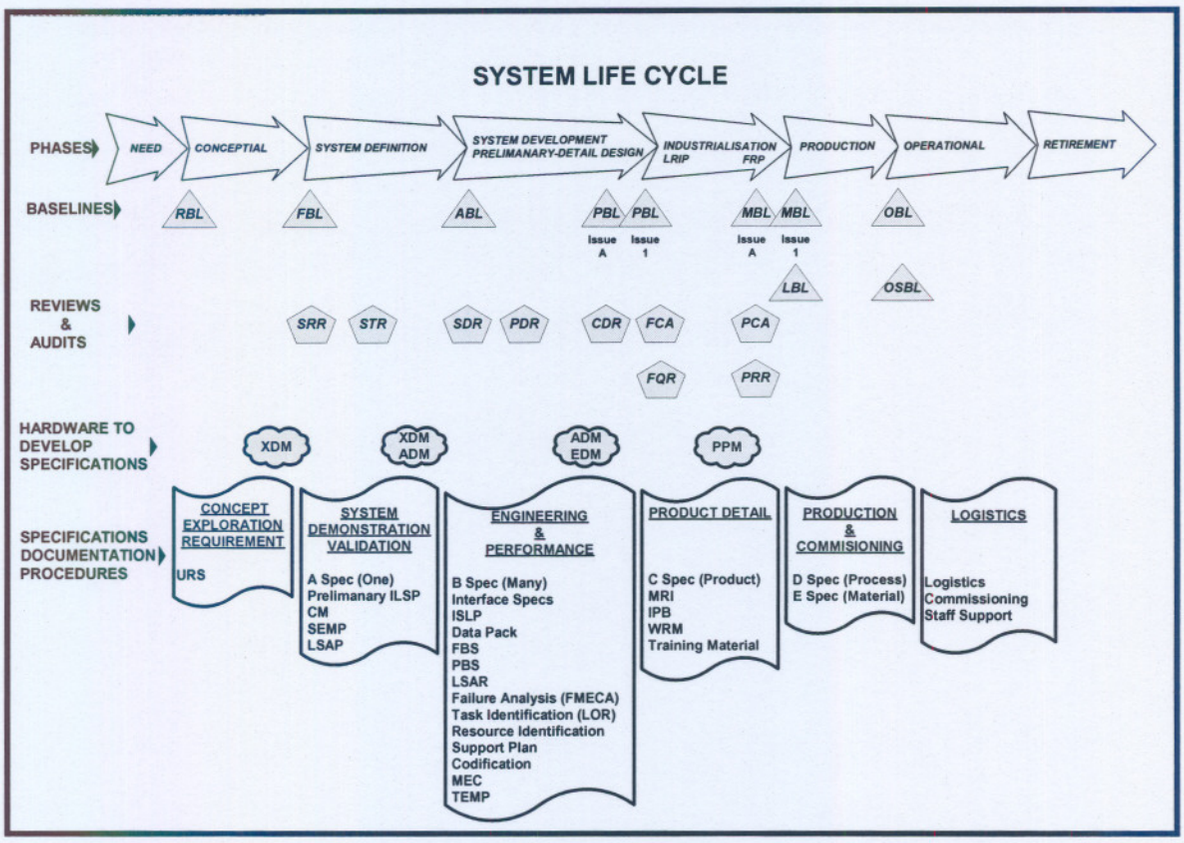


Figure 1: System Life Cycle

It is evident that these Systems Engineering processes consist of the building of a few hardware models before it eventually leads to the production of the final product. This hardware is used to develop the relevant phased specifications.

Laboratory and field tests are performed on the hardware and the results are used as a system design feedback. The Experimental Development Model (XDM), the Advanced Development Model (ADM), the Engineering Development Model (EDM) and the Pre-Production Model (PPM) are hardware models that are used for evaluation and the obtaining of answers to questions as the project progresses.

Building these hardware models is a costly and time consuming business. The results obtained frequently lead to the amendment of specifications, the requesting of concessions, or the processing of Engineering Change Proposals (ECP). Often design changes and further improvements are unnecessary time and cost consuming processes. However, the development of GAMA by means of simulation and testing reduced the need for ECPs.

Design flaws are invariably revealed by processes such as Failure Review Analysis and Corrective Action System (FRACAS) and corrected through the implementation of Corrective Action Requests (CAR). Such embarrassment could be avoided by using the power of simulation.

Technology today introduces advanced methods in the developing of systems. Simulation can and should form the basis for the development of new systems.

The extensive use of dedicated virtual prototyping simulation software packages and its ability to reflect reality is today actively promoted. Figure 2 illustrates the fact that the increasing availability of information reduces risk, which enhances competitiveness. [002]

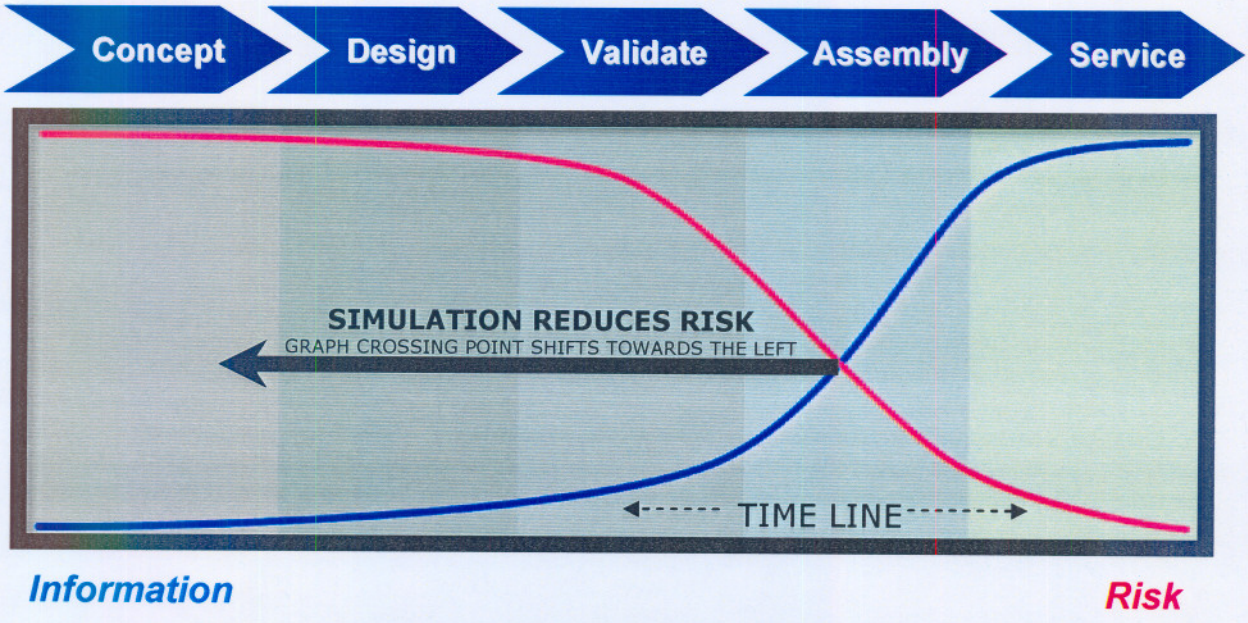


Figure 2: Correlation between Information and Risk

Laboratory and field test results are used as optional inputs for the simulation models. Simulation is an iterative process, which produces a scientifically matured system that enables the manufacture of a prototype that satisfactorily conforms to the client's request.

The development by simulation results in the rapid production of mature, reliable and safe systems. It can also be said that the longer it takes to make the correct decisions, the more costly it is to implement such changes. Simulation helps to make better decisions earlier in the development cycle of a project. Simulation therefore reduces the time line in the design cycle, and this in turn limits the production of prototypes, which results in the lowering of development costs. Simulation models now provide proper traceability throughout the development process, and are easily communicated across the various disciplines and departments. This addresses the question of archiving and save keeping as well.

The complexity in the development of a unique multi calibre weapon system, urges us to follow the route of development by means of simulation and testing. The reason is that the foreign 20x102 mm[1] ammunition was not available within the RSA and development could not be stalled awaiting the arrival of the new purchased ammunition. The importing of foreign ammunition requires the approval and the subsequent issue of End User Certificates.

The complexity in the development of the multi calibre weapon can best be appreciated when referring to Figure 3. This figure clearly illustrates the variance in shape and size of each round, each having its own unique performance.

[1] 20 mm Calibre with a cartridge case length of 102 mm



FLTR: 20 x 110 mm, 20 x 102 mm, 14.5 x 114 mm, 20 x 82 mm, 12.7 x 108 mm, 12.7 x 99 mm

Figure 3: Ammunition Requirement

Although the need was for the development of a weapon system capable of firing multiple types of ammunition, it was decided to shift the focus temporally away from the Soviet 12.7x108 mm calibre, due the present existence of the locally manufactured 12.7x99 mm North Atlantic Treaty Organization (NATO) approved ammunition within Denel's own inventory.

The life expectancy of a weapons system in general is also limited to the availability and the life expectancy of the specific ammunition it utilizes. Weapon systems designed to grow toward alternative or new types of ammunition are definitely an advantage. New ammunition may now through the agency of simulation be masterfully evaluated.

Adaptive procedures in ammunition handling, weapon maintenance and control procedures would be required, but the logistical support and training of personnel will only need to be limited to the amended procedures resulting from the incorporation of the new calibres.[003] Simulation as a medium also contributes towards the reduction of the time required to train

personnel. The development of GAMA establishes a process whereby the growth of any weapon towards the use of alternative ammunition can be evaluated.

1.2 Problem Statement

To design, manufacture and evaluate a new and novel weapon system that is capable of effectively operating within a specified range of ammunition.

ARMSCOR requested Vektor to develop a multi calibre, rapid firing weapon system that would be able to utilize 20x82 mm, 12.7x99 mm, 20x102 mm, 14.5x114 mm, 20x110 mm types of ammunition. [004]

The weapon had to be easy to maintain with minimum ground support equipment and special tools. The primary aim was for it to be fitted onto a Light Utility Helicopter for self defence purposes in air to air and air to ground scenarios. [005] [006] [007] [008]

The ammunition requirements were the neutralizing of and the protection against personnel, soft skin vehicles, buildings, helicopters and fixed wing aircraft. This protection was aimed at counteracting or stabilizing any situation forthcoming whilst performing civil support and military operations.

In addition, it was stated that it would be an advantage for this weapon system to be a replacement of the existing Gun Aircraft One (GA1) weapon and therefore be able to be successfully mounted on existing Air-, Naval- and Ground vehicles presently utilized by the SANDF. [009] [010] [011]

Before commencement of this study a thorough investigation established that a single rapid firing weapon system that could fire all the aforementioned ammunition, did not exist. [012]

1.3 Objectives

The design, development, manufacturing and the testing of a single weapon system that could:

- Fire multiple types of ammunition available throughout the world.
- Establish a design philosophy and process for the development of other weapon systems where design changes and ammunition expansions must be easily accommodated.
- Prove that simulation and testing methodologies can be used as a means to minimize the building of experimental hardware.

In addition, interfacing this weapon system with existing platforms was considered to be an advantage, and existing building blocks should be used as far as possible.

Information obtained during the development of the GAMA was readily available for the parallel development of the Vektor's Unique Intelligent GAMA Soft-Mount (Cradle). [013] The soft mount addressed the goal in dramatically reducing the system recoil forces, optimizing the dynamic behaviour of the gun, by automatically compensating for the variety of ammunition being fired. The advantage of having a soft recoil system is already being widely published. [014]

1.4 Contribution of this Study

This study resulted in the production of a weapon system capable of being deployed anywhere in the world utilizing either local or foreign ammunition.

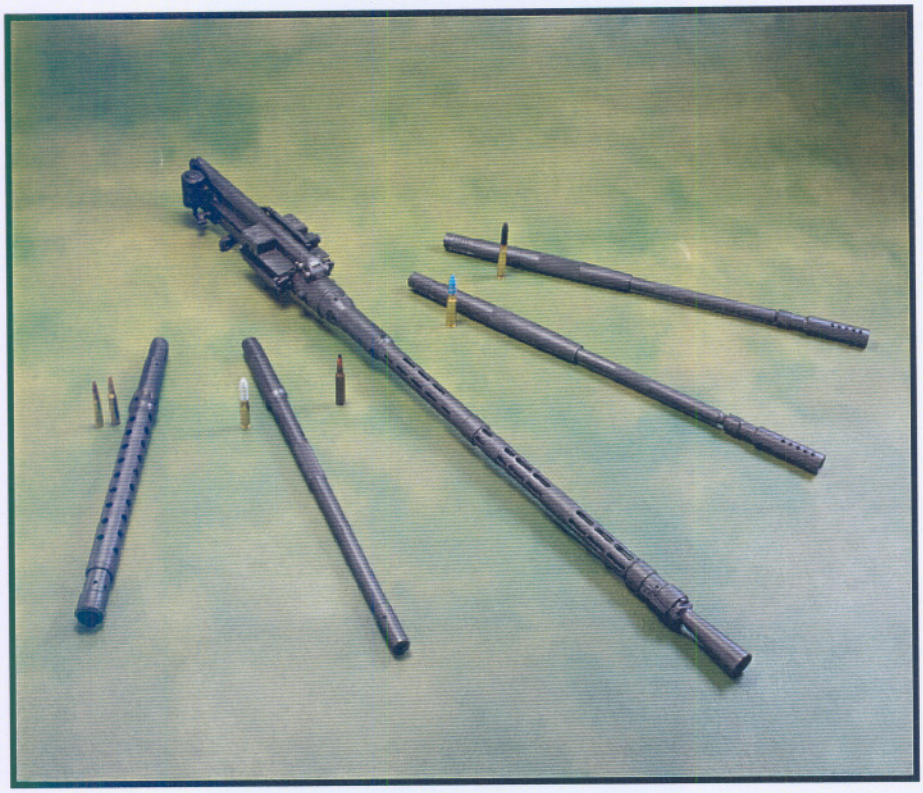


Figure 4: GAMA Illustrating its Full Capability

The uniqueness of the development of the GAMA can be underlined by the following achievements:

- The GAMA itself is unique in that no weapon with its ability has ever existed before. The literature study carried out by an independent information specialist confirms this statement (Annexure C). This weapon fulfils the role it was invented for, i.e. firing various types of ammunition, which no other weapon has been able to do up to now.
- During the time when GAMA was developed, simulation was not as advanced as it is today. Consequently, prototype hardware had to be subjected to both laboratory and field tests in order to facilitate the proper development of any system such as GAMA. The modus operandi disclosed by this study effectively demonstrates the competent interaction accomplished through simulation and testing.

- Simulation models were created that enabled future development with respect to any further changes in client requests. Behavioural changes within the weapon, with respect to the laid down constraints, can now be evaluated.
- The complexities of the situation prior to 1998 resulted in a development programme that was unique in the world for this kind of product.
    - Data manipulation had at times to be effected through the usage of unconventional methods which involved the customization of available software packages. Obtaining simulation software for the development of armament was accomplished under duress for obvious reasons. In order to circumvent the problems experienced in obtaining either software or ordnance, unorthodox methods were invariably used.
    - The development of the GAMA proceeded regardless of the fact that limited variants of ammunition were available at the time. A prototype of the weapon was manufactured and scheduled for field tests. Foreign ammunition was only delivered during the course of the field test and was fired with satisfactory results. The successful completion of GAMA can be directly attributed to the usage of simulation, which was unique at the time.
- The successful development of the GAMA was based on unique structural and motion analytical procedures that were actually developed by the author for another high profile technological project which preceded GAMA. [015] These procedures were so new that they resulted in a marketing drive by both LIW as well as Denel, who used them to promote their ability to address commercial needs for the future (Annexure E).

1.5 Brief Overview of Dissertation

1.5.1 Introduction

Chapter 1 of this dissertation deals with the Background to the project and the Problem Statement, as well as describing the unique contribution of this project.

1.5.2 Literature Study

Chapter 2 describes the Literature survey that was carried out to ascertain the state of the art in the industry as far as this weapon was concerned, as well as the scientific and technological processes that were in practice internationally. A part of this investigation was carried out by an independent contractor.

This Chapter also describes the background to the use of simulation methodology.

1.5.3 Characterizing of Baseline Weapon System

Chapter 3 describes the characterization of the baseline weapon, which was the GA1.

The GA1 was chosen as a suitable baseline weapon system on which the development of a multi calibre rapid firing weapon system could be based. 20x82 mm ammunition does not have the capabilities that newer generation ammunition has, and the GA1 is limited to utilizing such ammunition. The GA1 lends itself to the GAMA project by virtue of a number of factors:

- Simplicity of the weapon.
- Few operating parts.
- Availability of the weapon within the current inventory.
- Significant growth and expansion potential.

The GA1 weapon system was instrumented using various transducers to provide the required test information. The data was captured while firing the weapon system under normal operating conditions. The accumulated data facilitated the construction and the evaluation of simulation models.

The GA1 weapon was also fired rigidly obtaining data which is equally important for the parallel development of the GAMA soft-mount (cradle).

1.5.4 Modelling of Baseline Weapon System

This is described in Chapter 4.

Sophisticated virtual prototyping simulation packages such as Nastran, Mechanica and Adams were used throughout this development. These simulation packages, which interface with the available three dimensional (3D) parametric Computer Aided Design (CAD) packages, were used to simulate the existing weapon's structural and dynamical behaviours. The modelling process iterated between measured -, Finite Element - and Dynamic Analysis results.

Simulation model results were compared to the measurements of the actual weapon's performance. Models must behave in accordance with the actual hardware. Minor calibration adjustments were required to adjust the numerical models to follow the measured structural and dynamical behaviour of the baseline weapon system. Once the simulation produced a true representation, the design of the new weapon system commenced.

1.5.5 Design and Construction of New Weapon System

After the baseline weapon was successfully simulated, this information was used to design the new GAMA. This is described in Chapter 5.

The calibrated simulation models were stimulated, simulating the effect of firing the new ammunition. The design process, again, was an iterative process that included the utilization of Finite Element and Dynamic Analysis. The operation of the new weapon system was simulated against the established boundaries in which the weapon had to be operated.

Building a prototype system and subjecting it to live firing tests verified the development of the new weapon system. It was gratifying to see that the results obtained authenticated the design of the various simulation models with a view to addressing aspects such as future expansion or additional requests. The degree of flexibility attained can only serve to extend the life span of the weapon system.

1.5.6 Conclusion

In Chapter 6 the conclusions of this research and development are given. This chapter also gives a brief historical overview of the entire project, as well as making recommendations for further actions that are required.

CHAPTER 2 LITERATURE STUDY

Upon receiving the request for the development of a Multi Calibre Weapon System from ARMSCOR, literature available within Vektor was studied to establish whether such a weapon existed anywhere in the world.

Vektor (a Division of Denel) is currently South Africa's main developer and manufacturer of small to medium calibre military weapon systems. Vektor was previously a business unit of LIW[2] and is in the possession of literature for the development and manufacturer of small, medium and large calibre weapon systems. This literature not only covers established development processes, but also contains academic textbooks which assist the development engineer in performing his duties to his full capacity.

Vektor's Information Centre is also a subscriber of many magazines, booklets and books that are related to the armament industry worldwide. However, this literature search was not limited to paper copies only, and included the electronic media to its fullest extent.

2.1 Research for a Multiple Calibre Rapid Firing Weapon Systems

The author subcontracted Erna Meyer, an Information Specialist from the CSIR, as an independent researcher to assist in the scrutinisation of the media for the possible existence of such a weapon system (Annexure C). Searches were performed exploring the paper and electronic media covering the development of any multi calibre rapid firing weapon system by means of simulation and testing.

[2] LIW and Vektor merged in April 2005 to become DLS Lyttelton

Various databases and advanced search engines were used in the search for the existence of such a development. During the search, keywords in various combinations were used. The variation in spelling of certain key words was also introduced to broaden the search field. International academic, inter-disciplinary, military and patent databases were covered. Due to the level of the study, local and international dissertation databases were also searched to verify if this unique topic was not already registered as a PhD Thesis.

Subsequent publications of the work covered by this dissertation ensured that the successes of the GAMA project have been disseminated throughout the world (Annexure D). The uniqueness of this project was confirmed by the fact that no similar project has since been found in any other publication.

2.2 Existing Development Methods

The development of weapon systems may vary dependant on the infrastructure, tools and equipment available to develop weapon systems conforming to international standards.

Key constraints in the GAMA project related to weapon mass, recoil force and recoil distance. These phenomena have to be kept to a minimum in order to optimise a level of flexibility which is acceptable to all end users. The weapon needs to have few components, be easily maintainable and be capable of delivering acceptable dispersion and accuracy for marine, air and field operations.

Development processes within the armament arena seem to be a trade secret which can not always be obtained from literature and electronic media. Since marketing information does not divulge the differences in the developmental processes, comparative studies were unfortunately not possible as far as that was concerned.

The competitive market for weapons abroad has evolved a traditional design philosophy which has contributed to the successes obtained in the past. This has served to stultify any experimentation into the direction of simulation as a design process, since little of this has been known to date.

It has been noted by the author that often individuals that are responsible for defining or performing System Engineering duties, adopt only certain aspects of this process to the exclusion of others, and develop personal preferences as to what offers overall project success. For example, frequently the building of hardware prototypes is over-emphasised at the expense of simulation. Unfortunately, in the author's experience, when such engineers are questioned about their practices, the response is typically one of evasiveness. For example, the following arguments are usually offered:

- The philosophy of simulation is brought into question.
- It is stated that "the client's needs are the focal point of every project". However, sometimes a request from a client will be accepted for execution, whereas simulation could have shown that the request is not feasible.
- The importance of "total life cycle design" is emphasised, but this does not include simulation as a part of System Engineering. However, it can be demonstrated that simulation could contribute significantly to the identification of necessary logistical support (such as provision of spares, and need for maintenance) throughout the life cycle of the product. [016]

The introduction of simulation methodology within a developmental facility is more often than not complicated by subtle factors such as the following:

a) Job security of personnel. Production personnel, who are always closely involved in the manufacturing of development hardware (mock-ups), feel threatened. It is invariably found that with simulation costs are cut due to a reduction in the production of prototypes that are required for the manufacture of a final product for example: the Airbus 380. [017]

b) Management is too concerned about the high initial cost of these simulation packages, without realising the benefit that these packages could offer with regard to important issues such as cost reduction and time management. Management tends not to see it as a part of the infrastructure (tools and equipment), when in fact the purchasing of these multi-functional simulation packages will advance development in general. At present the tendency is to divert costs to individual projects. This is unreasonable. Utilizing the software for extensive periods on a project is more important than needing the software for short periods to produce the required results. A change in perception needs to occur with regard to the acquisition of software packages, in that:

- They will be readily available for other projects
- Productivity will be enhanced by virtue of time saved and not time used.
- Results attained in projects will be available for usage in a multi – disciplinary environment.

The traditional way of development involves the parcelling out of tasks to individuals focussing on their fields of expertise. Simulation on the other hand will stimulate the broadening of knowledge within the development environment that will result in a more flexible work force.

c) Often the manufacture of developmental hardware takes precedence over simulation, whereas a useful result can just as well be achieved through the usage of simulation software. This would result in a significant reduction in costs across the board. Simulation, for some reason or other, is likened to playing computer games. This result in inadequate time being set aside for simulation, whereas manufacturing always enjoys predominance as far as time is concerned. Progress is invariably assessed by tangible means, and unfortunately this relegates simulation to an unacceptable level. It is easy to lose sight of

the fact that often the hardware has to be reworked to achieve an acceptable result. Education with respect to the power of simulation needs to be emphasized and hopefully this will result in a different management style as far as contract planning is concerned.

Simulation is software dependent where models / programs are generated to predict system performances and responses. A cautionary statement is appropriate: "Reliance solely on numerical values of simulation and analysis should be avoided. Based on the past history, software development is often a high risk area. Among the causes of performance, schedule and cost deficiencies have been:-

- Imperfect understanding of operational requirements and its translation into source instruction.
- Risk tracking and handling.
- Insufficient comprehension of interface constraints.
- Lack of sufficient qualified personnel". [018]

The development of products follows the process of Systems Engineering Management that consists basically of three activities known as:

- Development Phasing
- System Engineering Process
- Life Cycle Integration.

Development Phasing addresses a flow of activities covering concept studies, system definition, preliminary and detail design.

System Engineering, in theory, describes a process that will ensure success by illuminating risks that manifest themselves unexpectedly as unknowns that were not previously catered for. These risks are incidences which always lead to unfavourable consequences. The knowledge of risks reduces the negative results with respect to the progress and performance of a project. Much has been said regarding risk management which emphasizes the Planning, the Monitoring, Accessing and the Handling of risks. Currently,

the identification of a risk, depends greatly on testing and not enough emphasis is placed on simulation, which, if used, would identify and eradicate these risks well in advance.

Life Cycle Integration ensures that the design solution is feasible throughout the total life of a system.

2.3 Available Design and Simulation Approaches

2.3.1 The General Simulation Environment

At present it is found that the use of Finite Element Analysis (FEA), Dynamic Analysis, manufacturing and the execution of laboratory and field tests are distributed among different individuals who are managed by different departments. Development involves the scheduling of these departments, each of whom has their own skills priorities and agendas. Ensuring the success of the project therefore often requires a project manager on an executive level to manage the project schedule across various departments.

Although it is known that Finite Element Analysis, Dynamic Analysis and Experimental Testing are powerful tools when utilized independently, a superb foundation for simulation is offered by a knowledgeable individual whose skills include:-

- A full understanding of testing and its environmental constraints.
- The metallurgical behaviours of materials.
- An in-depth knowledge of other engineering disciplines.

One single simulation model can now be used to evaluate the modular designs with respect to the structural behaviour of a system, its dynamical response and the control algorithm. Once this design for each module (e.g. cannon, radar etc.) is successfully evaluated, the prototypes can be manufactured.

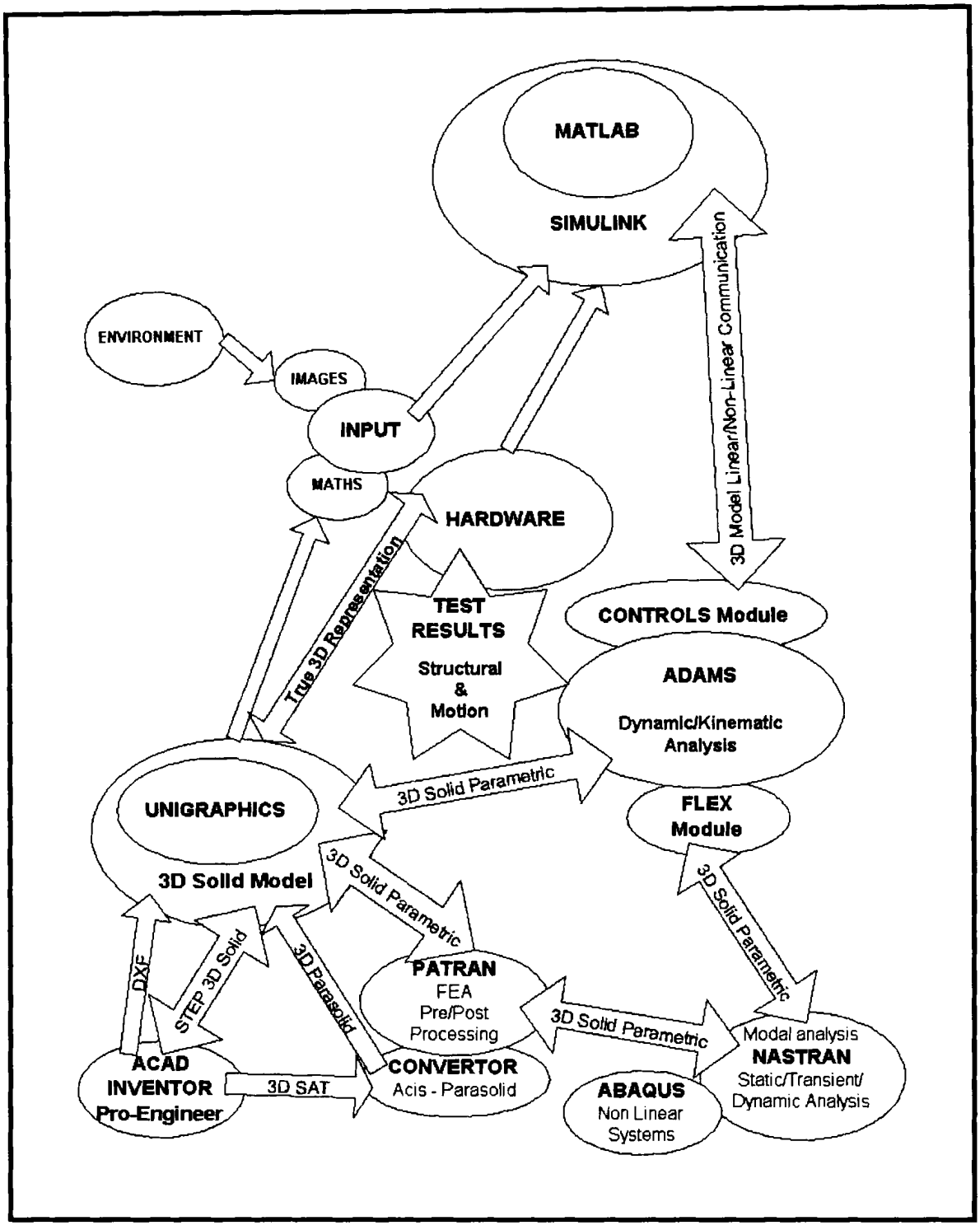


Figure 5: Graphical Representation of Simulation and Testing

The entire simulated system can now be physically assembled by systematically replacing each simulated subsystem or module with its distinctive hardware ("hardware in the loop"). Reduction in the risk of failure

is significantly reduced by the systematic replacement of modular hardware. Through this process a mature system can be delivered.

The development of GAMA was enhanced by the fact that an individual (the author) possessed multi - disciplinary credentials. This created an environment where personnel from different disciplines were able to interact with him freely thus enhancing the overall developmental process.

Typically the modular interaction between simulation and testing during development is visually represented in Figure 5.

2.3.2 Finite Element Analysis

Finite Element Analysis is a predictive Engineering approach, simulating the performance characteristics of any design before it is manufactured or even before a prototype system is physically developed. Structural and Thermal evaluation and optimization are made possible when interfacing within the CAD environment. FEA enables the engineer to accurately identify stress distributions, reaction forces and structural deformations through Static-, Transient- and Dynamical Analysis. The theoretical evaluation of a structure or components with regard to their modal behaviour, frequencies and shapes is also easily attained.

The environment can also be adjusted to enable the evaluation of structural behaviour within different scenarios. FEA is widely used to resolve basic problems in structures.

To use FEA to its fullest extent requires the inclusion of knowledge from other disciplines. For example, the incorporation of electrical/electronic-, metallurgical- and chemical engineering would result in better and more useful simulations.

The combination of FEA (with the practical evaluation of structural stresses and frequencies when applying strain gage technology), with Modal Analysis software (using a spectrum analyser, signal generator and shaker) as well as other measuring techniques, not only confirms theoretical results but also assists in the calibration of models for the development of critical and dangerous equipment.

The Photoelastic Test Procedures are also used to determine stresses:-

- Photostress method
- Two Dimensional Model method
- Three Dimensional Model method [019] [020]

The surface coating method provides a test technique where surface strains are measured when the structure is statically or dynamically loaded. The strain sensitive plastic coating is bonded to the component. While loaded the coating is illuminated by polarized light from the reflection polariscope. Colourful strain patterns are visible when viewing the test piece through the polariscope which reveals all the highly stressed areas. [021]

The 2D and 3D model method refers to a process when a part that is normally fabricated from a homogeneous material (e.g. most metals including steel and aluminium, rubber, glass and most plastics) is modelled from photoelastic material.

As before, the model/test piece is loaded while the polariscope is used to identify the stresses. [022] Figure 6 illustrates the latter method performed in DLS Lyttelton Laboratory, evaluating a component under development. Stress concentration in terms of its location and magnitude is clearly visible using the polariscope. [023]

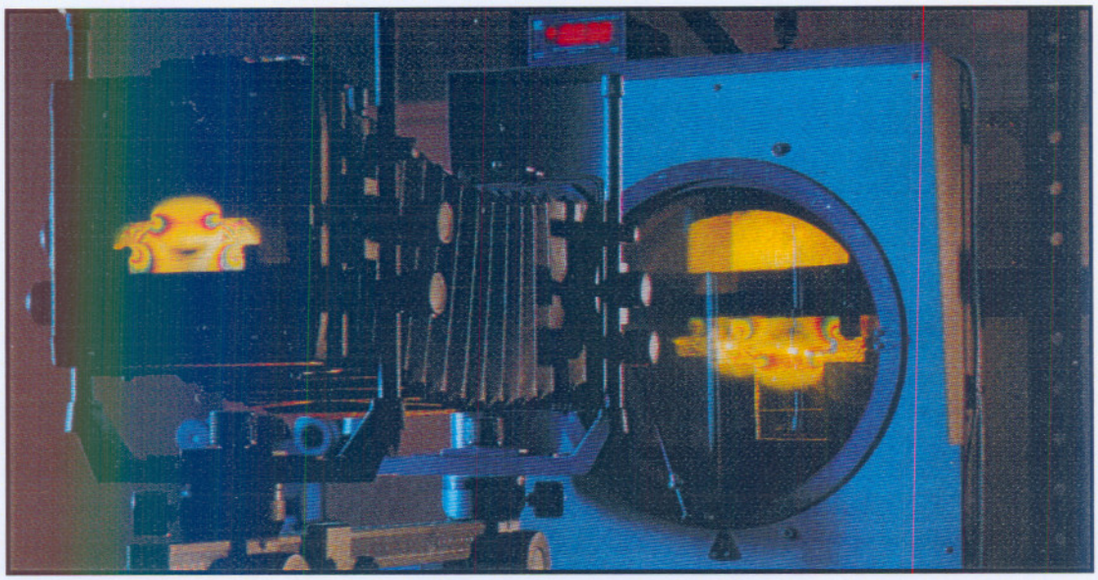


Figure 6: Photo-Elastic Stress Analysis

Preference is given for use of FEA methods when resolving linear and non linear systems. Motion Analysis interfaces interactively with FEA Software Packages and Control Software packages.

2.3.3 Motion Analysis

Any mechanical system with various masses can be mathematically assembled using predefined interfaces, such as couplings, cams, slots, springs etc. A simulation model can then be used for the accurate evaluation and optimisation of the dynamic and kinematic behaviour of such a system. This is called Motion Analysis. This simulation method, although new, is currently being used in the development of new systems. Flexible bodies can also form part of the dynamic solution of the system. System control algorithms which interface with Matlab can also form part of the design and optimisation. This method of design allows the engineer to alter design variables, including environmental conditions. It is a powerful simulation tool.

The interactive utilization of Motion Analysis, Finite Element Analysis, laboratory and field tests can result in enhancing the process of simulation. This allows the engineer to calibrate models before they are used as a blueprint for the development and resolution of dynamic structures.

The concept of interactively using FEA and MA together with Test and Evaluation methodologies will be illustrated during this project. The development of the unique multi calibre weapon system is initiated by characterizing a baseline weapon system, from which simulation models are generated and calibrated. The success of the GAMA is demonstrated by the very fact that it was built and fired successfully. This dissertation covers all the developmental phases used to achieve success.

CHAPTER 3 CHARACTERIZING THE BASELINE WEAPON SYSTEM

Before any simulation model can be designed, a full understanding of typical hardware behaviour is essential. It is no use performing a numerical exercise when the theory and the practice do not conform with each other. It also helps the developmental engineer, in that it prevents him simulating in the finest detail something that cannot always be verified. This culminates in unnecessary time consumption on trivial issues that really do not have any effect on the performance of the hardware.

3.1 Description of Weapon

The unit chosen as the baseline weapon for the GAMA project was the GA1. This weapon system was originally based on a weapon called MG151.

In 1935 the Mauser Company was given the assignment to develop an automatic gun capable of firing a 15-mm high velocity cartridge. The main purpose of this gun was to have an intermediate weapon which could be used by the German Air Force. This newly developed aircraft gun was a short recoil, air cooled system having a rotating bolt head for locking. [024]

The weapon developed a firing rate of approximately 700 rounds per minute utilizing a metal disintegrating push-out type supply link. The Mauser Company designated this new development as a MG-151[3]. Although great successes were achieved with the mechanism of the weapon, problems were experienced with its rifling. The size of the projectile also made it difficult to accommodate a fuse for a high explosive charge.

[3] "MG" Represents Maschinen Gewehr or Machine Gun the "15" for the bore diameter and the "1" represent the first model.

This resulted in a decision by the German Ordinance Department to put every effort into increasing the 15-mm bore to 20-mm bore, which put this weapon into the automatic cannon class. Although the preferable designation of the later decision would change the "MG" status to "MK" (Cannon) status, it was universally known as MG-151 20-mm aircraft cannon. The weapon is equipped with a quick change barrel and electric ignition. A driving spring in the cover group actuated the breech bolt assembly that can be completely removed when the cover is raised. A push out type link with a snap action at the rear prevents misalignment. These are some of the outstanding features of this weapon system. [025]

The MG151 cannon, firing percussion type primer ammunition, was later manufactured as the GA1 by Vektor, which is the main manufacturer of small to medium calibre weapons for the South African National Defence Force. This weapon was mainly utilized on the Allouette Gun Ship Helicopters and later deployed on Infantry and Naval combat vehicles.

The GA1 is a recoil-operated weapon system. A recoil-operated system implies that the barrel and the breech, which are initially a locked entity, are driven back by the gas pressure during launching of the projectile. [026] [027] The initial recoil motion of the barrel and breech assembly is solely responsible for the cycling of the weapon system during firing.

Figure 7 shows that the weapon consists of 5 major groups:

- Barrel assembly,
- Feeder housing cover group,
- Receiver group,
- Breech bolt mechanism group
- Feed chute. [028] [029]

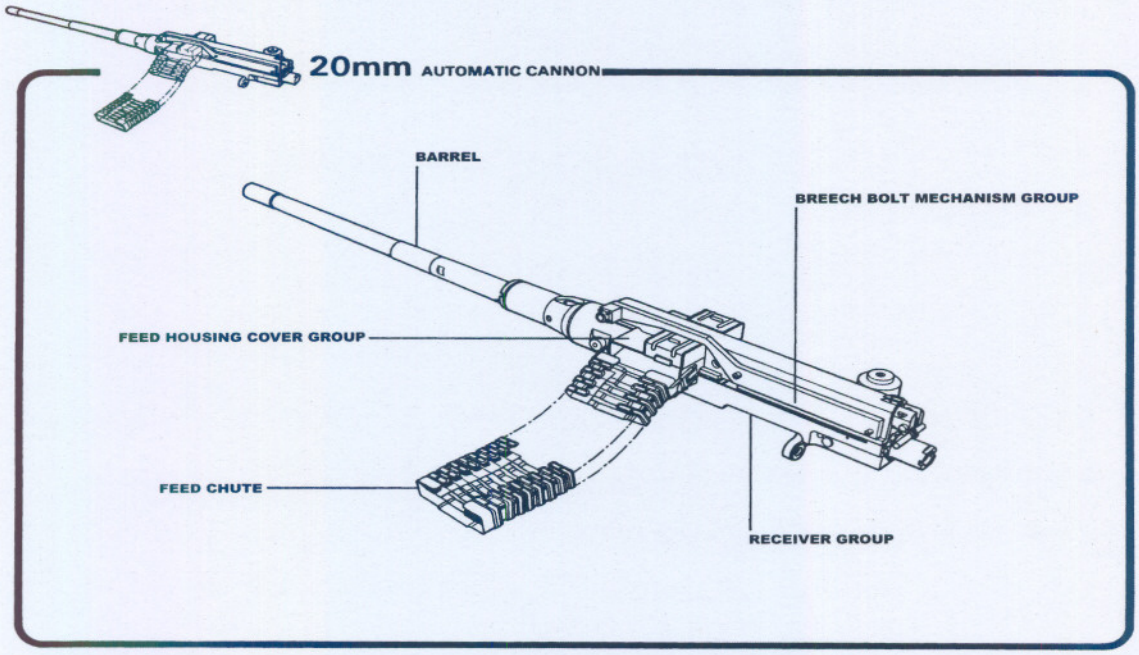


Figure 7: Weapon Description

The barrel (Figure 8) directs the discharged projectile. The knurling on the barrel is to facilitate turning during replacement. The rear enlarged fluted bearing section makes contact with the barrel buffer thrust collar stopping its recoil.

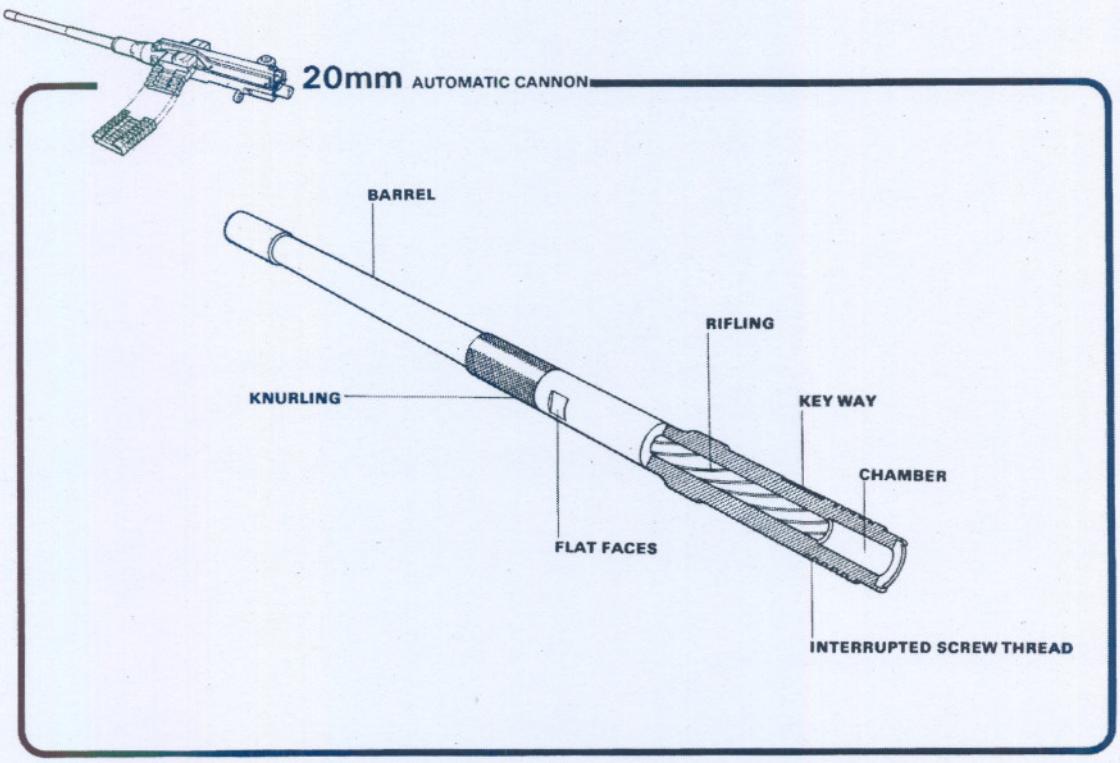
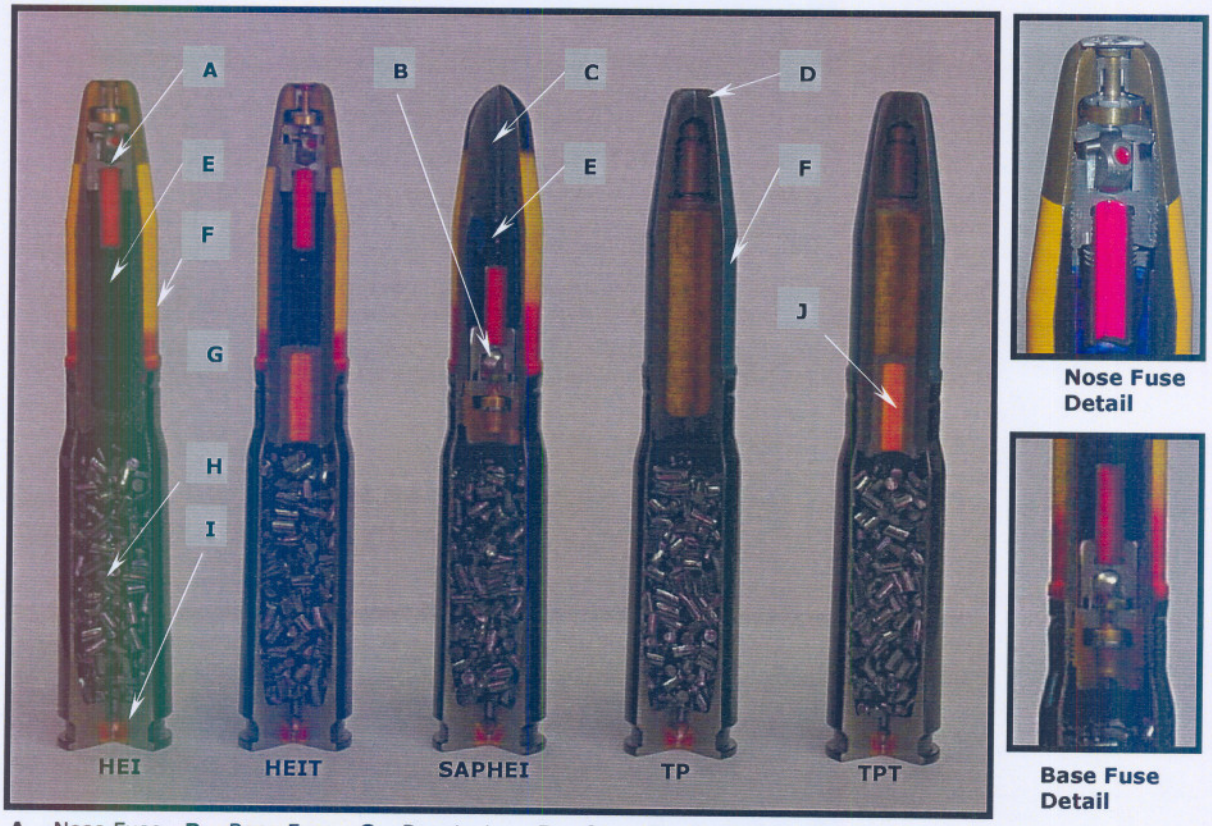


Figure 8: Barrel Assembly

Multiple buttress lugs at the end of the barrel - also known as interrupted screw thread or comparties - mate with the receiver bushing assembly within the barrel extension assembly. The barrel catch prevents rotation thus preventing accidental disengagement during operation.

The projectile is spun by rifling in the barrel, ensuring adequate stability during launch. The projectile spinning action also arms the nose and base fuses of the projectiles that containing explosive charges, as seen in Figure 9.



A – Nose Fuse **B** – Base Fuse **C** – Penetrator **D** – Cap **E** – Explosive **F** – Shell
G – Case **H** – Propellant **I** – Primer **J** – Tracer

Figure 9: Sectional Views of 20x82 mm Ammunition

Ammunition types (Figure 10) that is fired during operations and training is High Explosive Incendiary (HEI), High Explosive Incendiary with Tracer (HEIT), Semi-Armour Piercing High Explosive Incendiary (SAPHEI), Amour Piercing (AP), Target Practice (TP) and Target Practice with Tracer (TPT). Reference and High Pressure (HP) Proof rounds are used during proof and commissioning of systems.



Figure 10: Typical Ammunition Fired

An additional safety feature is achieved by the small projections at the end of the barrel. These projections prevent the proper engagement of the breech bolt head within the receiver bushing assembly when the barrel is not properly secured.

The multi functional hinged cover group contains the electrical trigger control interface, ammunition feed system (Figure 11) and the recoil mechanism (Figure 12).

The front hinge of the cover is secured to the receiver with a removable pin while the cover locking catch secures the cover at the back of the receiver in the closed position.

The electrical control interface enables the gunner to activate the trigger by means of a solenoid. This solenoid is activated by 28 V DC. Directing the

weapon, however, is dependant on whether it is manually or remotely controlled.

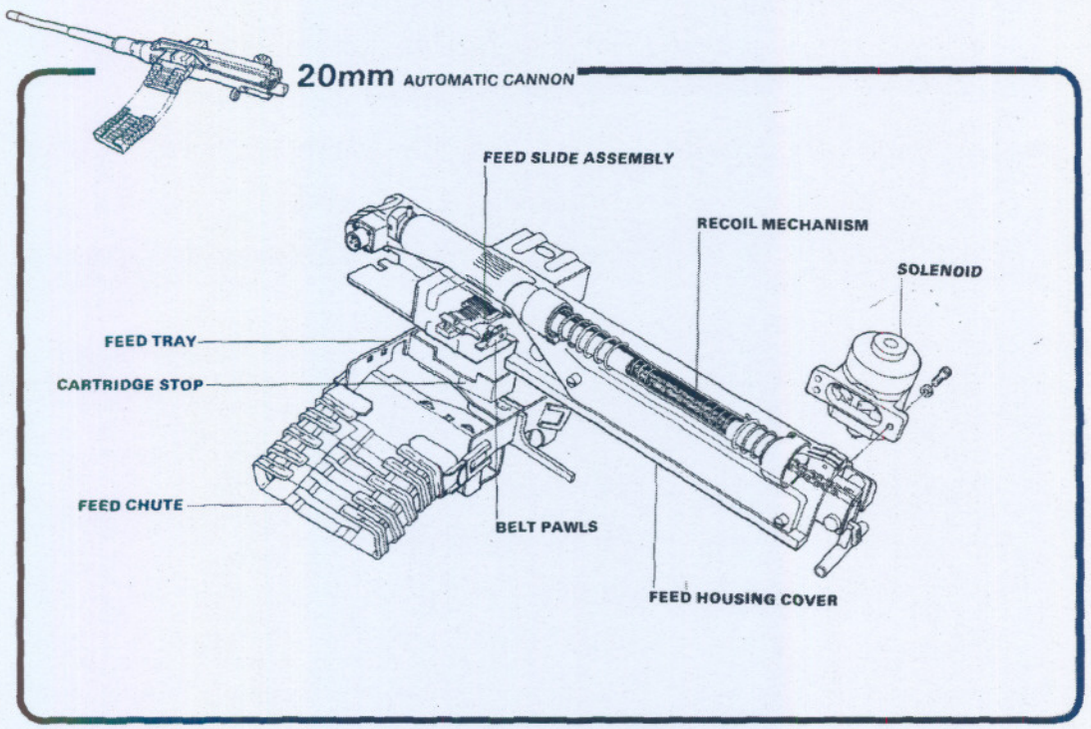


Figure 11: Ammunition Feed System

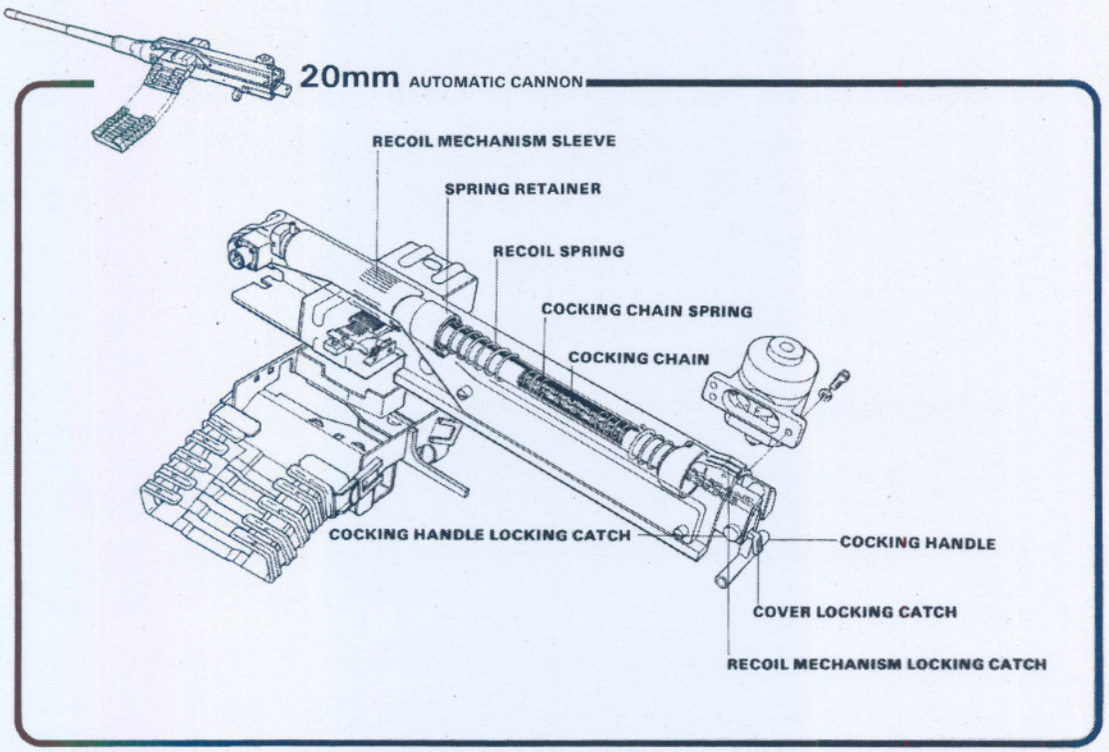


Figure 12: Recoil Mechanism

At present the South African Air Force Allouette Gun-ships are equipped with manually controlled pintle door mount systems. These helicopters are in the process of being replaced by Augusta helicopters on which remotely controlled chin mounts are proposed. Directing the chin mount system would be made possible by using a helmet sight which supplies the gun system controller with the direction algorithm. The gun system controller, after selecting the ammunition type, performs external ballistic calculations which ensure that the proper super elevation and the leading angles are acquired in order that first hit probability is attained.

The ammunition feed system conveys belted ammunition from the feed chute to the weapon. The feed tray consists of a feed way, ejector and cartridge stop. The cartridge stop stabilises the round enabling the breech bolt to drive it into the chamber where it is fired. A loaded belt must be preceded by five empty links to facilitate loading.

The toothed tube of the recoil mechanism sleeve interfaces with the slide rack of the feed assembly. The rotational movement drives the feed slide assembly back and forth in a sideways direction, pushing the linked ammunition along the feed tray, past the ammunition belt pawl assembly, and up against the cartridge stop. The pawl assembly secures each linked round firmly against the cartridge stop during stripping.

Replacing the recoil sleeve, which has a helical slot, allows ammunition to be fed from either the left or the right of the weapon. Rotational movement of the recoil sleeve is accomplished by having the spring retainer stud interface with the recoil sleeve helical slot. This stud duly interfaces with the breech carrier.

Translational movement of the breech assembly is directly converted into rotational movement of the spring retainer as a result of their direct interface.

Manual cocking of the weapon is obtained by pulling the cocking T-handle at the back of the cover. Cocking of the weapon drives the following round against the cartridge stop. Translational movement of the spring retainer compresses the recoil spring, which moves the breech assembly backwards, positioning the breech assembly firmly against the back of the sear from where the firing of the first round commences. A helical spring inside the chain guide ensures the retraction of the chain roller and T-handle when cocking is accomplished.

The discharged pressure of the propellant drives the breech assembly rearwards ultimately resulting in actuating the feed system.

The recoil spring within the recoil mechanism provides the forward motion to the retainer which drives the breech assembly in the firing cycle, accomplishing the stripping, the chambering and the firing of each round. The momentum achieved during the firing of the first round is solely dependant on this recoil spring's performance. Thereafter propellant gas is mainly responsible for the recoil motion of the breech assembly. The impact against the breech buffer, in conjunction with the recoil spring, now deflects it forward resulting in the subsequent rounds being fired. This motion drives the feed slide assembly, positioning the pawls behind the next belted round.

The receiver group (Figure 13) contains the sear, which when activated, allows the forward motion of the breech assembly to proceed without interruption achieving the completion of the firing cycle.

The barrel extension housing contains both the barrel's buffer and recoil mechanisms.

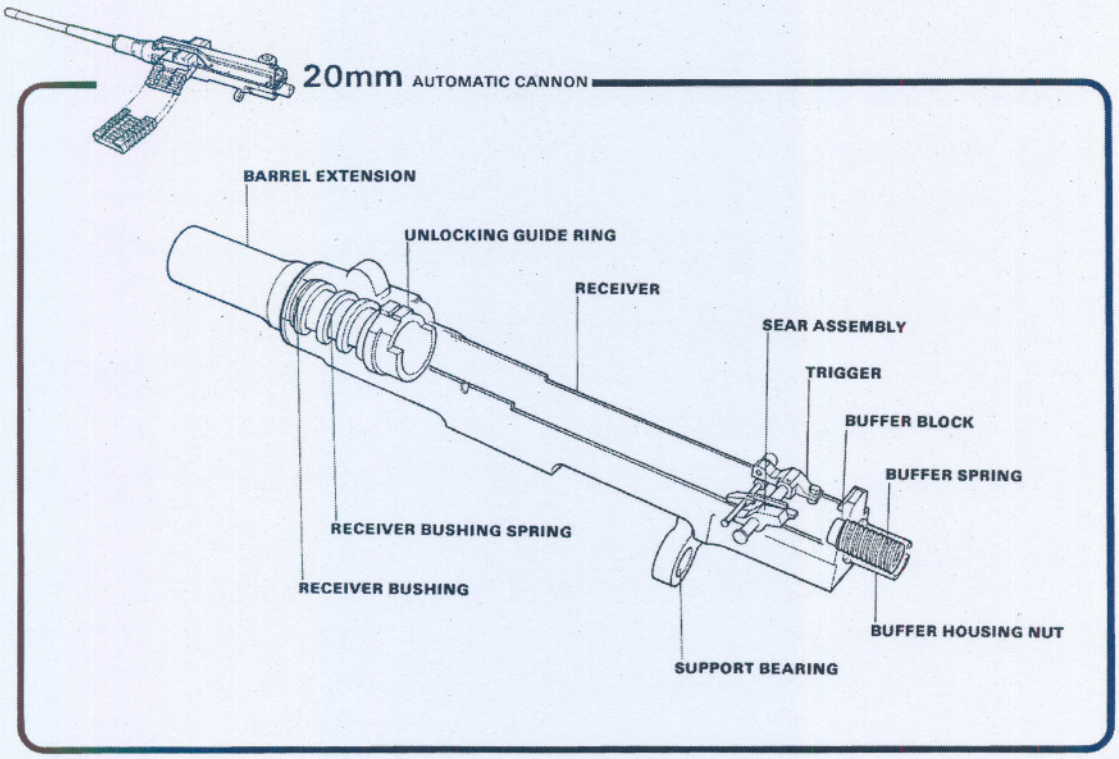


Figure 13: Receiver Group

The coercing recoil motion of the barrel and receiver bushing terminates during the unlocking action which is achieved by adequate rotation, disengaging the comparties of the breech bolt head from the receiver bushing. After separation the recoil of the barrel and receiver bushing is stopped by the barrel buffer, allowing the receiver bushing spring to return the barrel to its battery position.

The main function of the breech assembly (Figure 14) is to strip each round from the belt, convey it to the barrel chamber, fire the round and discard the empty cartridge case. Stripping is achieved when the round is forced forward by the breech bolt. During the stripping, the empty link is retained and secured by the belt holding pawls.

The round while being pushed forward is guided simultaneously by the cartridge ramp and feed tray feed-way towards the barrel chamber entrance.

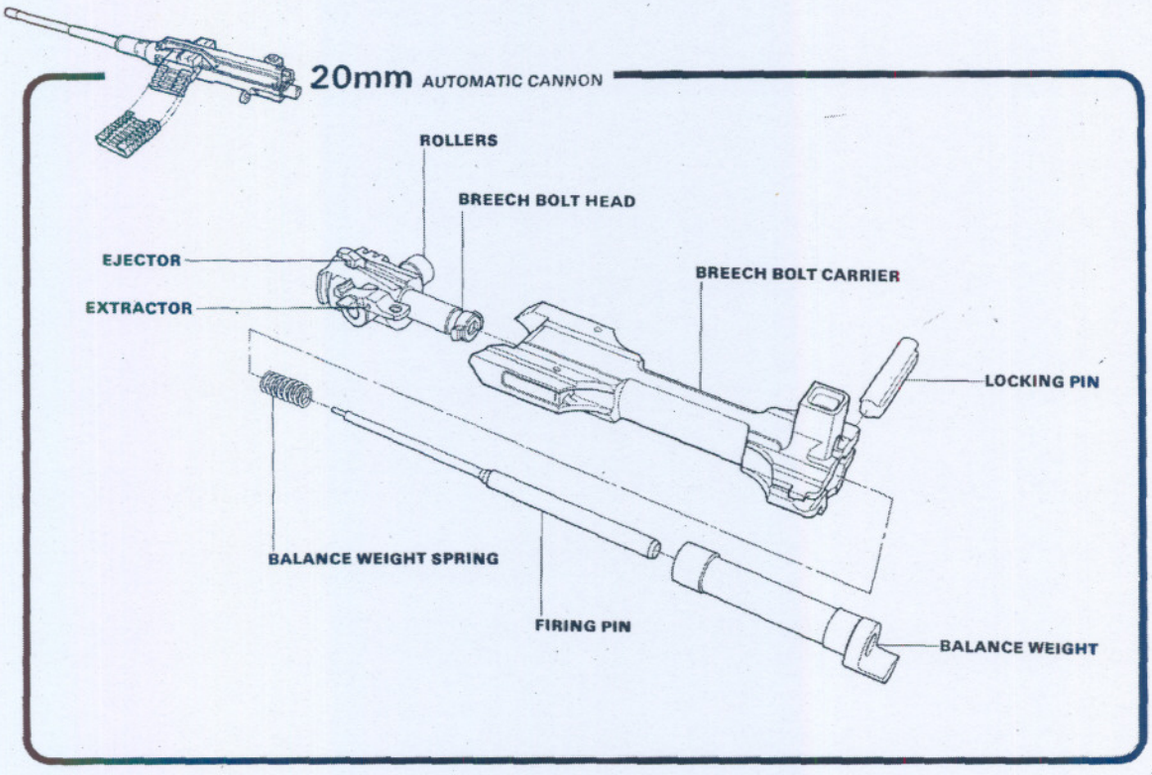


Figure 14: Breech Assembly

During this motion the cartridge case rear face progressively positions itself against the breech bolt head's bullet face until the cartridge case rear rim engages with the extractor.

Although the extractor is holding the round firmly against the bolt's bullet face, inadequate turning of the breech bolt head will prevent the extended breech mechanism assembly from collapsing. This in turn will disable the weapon from firing as it would be prevent the firing pin from striking the primer of the cartridge. Firing will only be possible when the bolt head is stopped by a fully chambered round, during which adequate case crush is obtained. Prior to firing the breech bolt head is rotated into a locked chamber configuration.

Rotation of the bolt head is achieved by having the side rollers of the bolt head wedged, resulting in a vertical motion by cam surfaces of the forward moving breech bolt carrier. The telescopic compressive motion between the

breech bolt head and breech bolt carrier is also made possible by the receiver bushing, allowing the bolt head to rotate approximately 30° in a clockwise direction while engaging with it's mating comparties in the receiver bushing into the full lock chamber configuration.

The tip of the firing pin is only exposed when the breech assembly is in its collapsed state. The difference in length causes the firing pin to protrude the percussion gap by a calculated amount, with the resultant activation of the primer, which sets the propellant alight.

The build up in pressure caused by the burning propellant launches the projectile along the rifling of the barrel. Simultaneously the counter reaction forces the interlocked barrel, the receiver bushing and the breech mechanism backwards.

Unlocking the breech bolt head from the receiver bushing is achieved by allowing the unlocking ring's cam surfaces to interface with the bolt head side rollers during the rearward motion. The unlocking ring induces an anti-clock rotational motion on the bolt head allowing the bolt head comparties to disengage from the receiver bushing. Simultaneously the bolt head side rollers pressing against the carrier's front nose cams extend the telescopic length resulting in the firing pin being withdrawn from the bullet face, disengaging from the now empty cartridge case.

The empty cartridge case remains firm against bullet face and is only discarded when the bolt head passes below the rear end of the feed tray. The feed tray ejector pushes against the breech bolt head cartridge ejector. A downward hinged action of the cartridge ejector pushes down the cartridge case to hinge downwards over the extractor, ejecting it through the lower opening in the gun.

3.2 Functionality of the Weapon

The functionality of the weapon is illustrated in Figure 15. Understanding the sequential flow of events enables the understanding of the weapon's dynamic behaviour. The GA1 consisted of roughly 218 parts. All the components were weighed, spring characteristics measured, while cross correlation between measured data and designer's data-pack data was continuously monitored. Measured data took precedence over data pack data when deviations were noted.

System identification started by dismantling and assembling the weapon during which the interaction of all components were noted. Dry cycling the weapon by hand, utilising belted dummy rounds, assisted in determining the true static behaviour of the weapon throughout the firing cycle. Simultaneously, the relative and absolute displacements among all parts within a reference Global Cartesian Coordinate System were also measured.

Intermediate position such as sear contact, buffer contact etc. was also noted. The foundation for the assembly of a simulation motion model is dependent on the information accumulated.

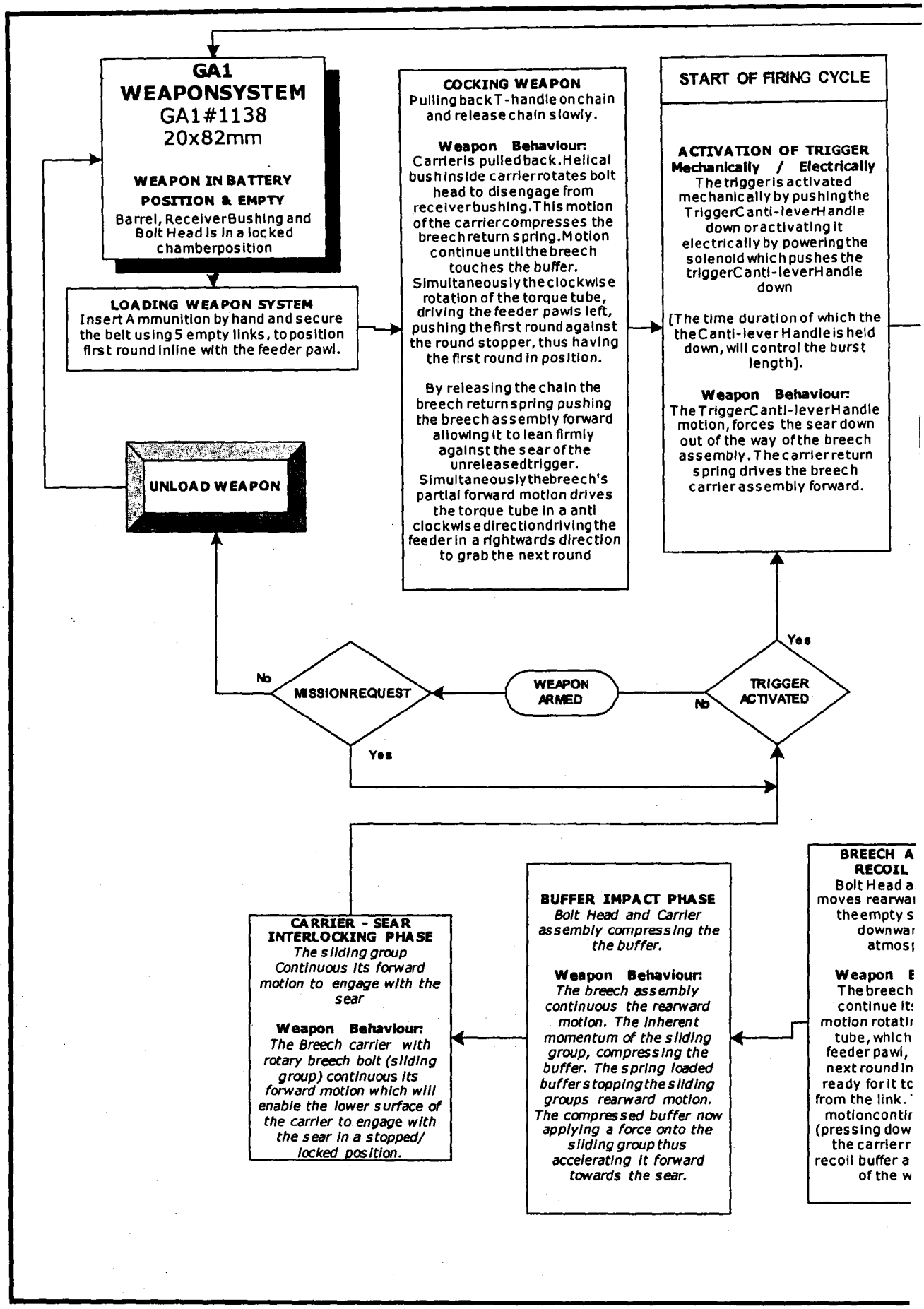
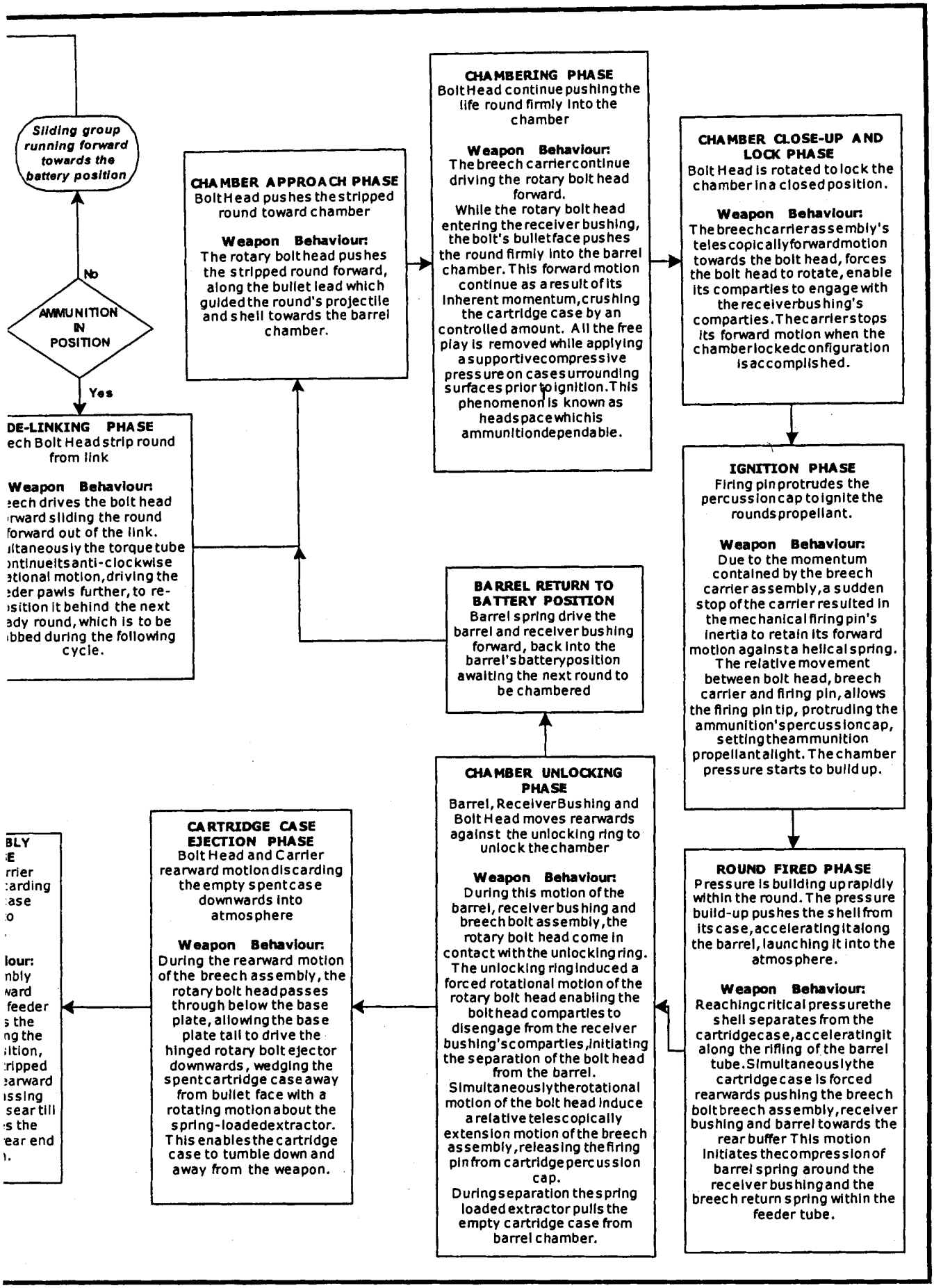


Figure 15: Functional Flow



ock Diagram of a GA1 Weapon

3.3 Testing of the Baseline Weapon

During the testing process data was captured manually and electronically using sophisticated transducers. The combined results allowed for the proper definition of the structural and dynamic behaviour of the weapon.

Gathering of information was not limited by some of the shortcomings that are often experienced during system identification (such as the shortage of data-acquisition channels, the lack of accessibility, transducer availability etc.). These invariably create problems, which will ultimately affect the performance of the model.

When such problems were encountered, sufficient corrective measurements were always taken to enable the exploration of the true behaviour of the weapon throughout each firing cycle. The basis for testing was to ensure that the data captured was usable within the simulation environment. Development, benchmarking, calibration and verification were then achieved through the agency of laboratory and field testing.

The author's experience in the field of structural and dynamical simulation, coupled with in depth involvement in field and laboratory testing, contributed to the proper definition of test specifications and procedures.

The acquisition of sophisticated testing equipment, ammunition consumption during testing, the usage of dedicated range facilities all contribute to the escalation of firing trial costs. These range facilities provide adequate infrastructure and logistical support necessary for development.

The equipment was always kept at optimum performance levels, by ensuring that it was regularly maintained and calibrated. By this means the integrity of data was kept at a level of credence that justified the confidence that was eventually put into it.

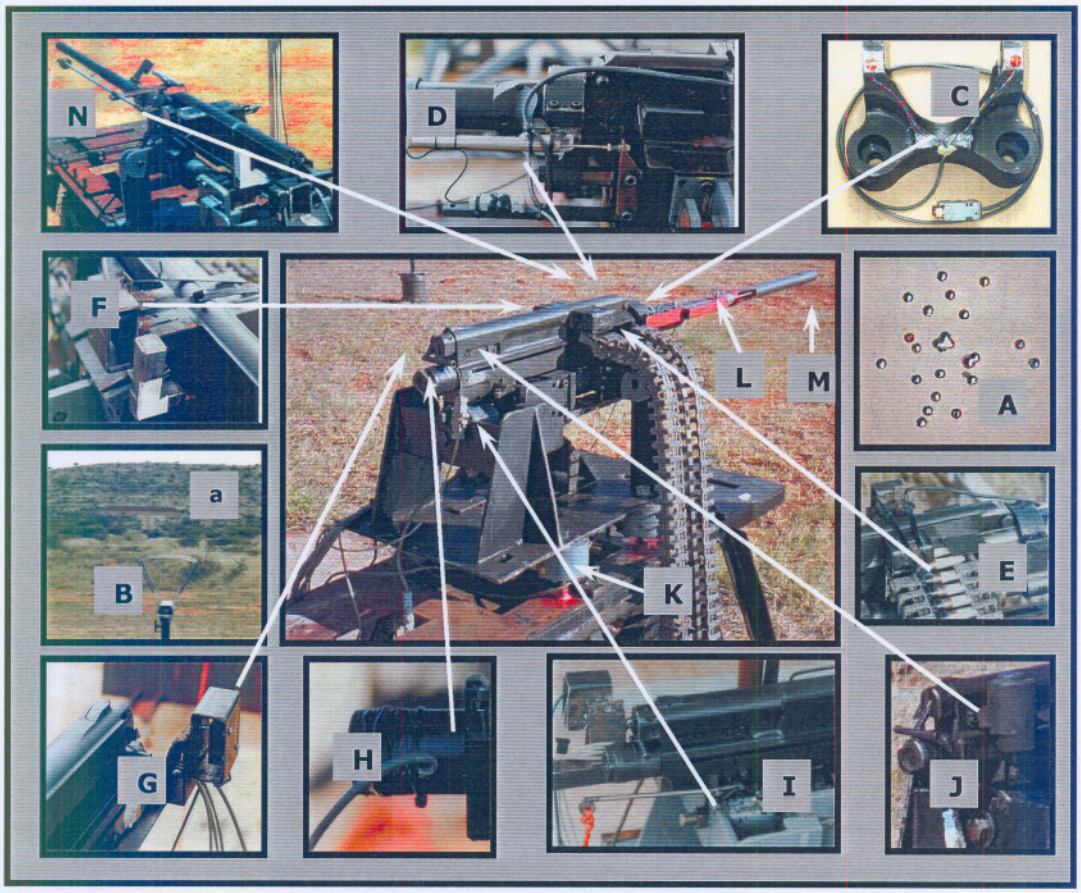
The volume of data generated during firing trials necessitates the usage of a comprehensive data base in order to be able to track or reconstruct events.

An illustrative reflection of a typical data base is annotated hereunder:

- Unique test number- for traceability and archiving purposes
- Weapons configuration
- Record of rounds fired
- Type of ammunition used
- Instrumentation usage, serial numbers and calibration
- Serial numbers related to weapon hardware and replacement spares
- Stoppages and corrective actions performed
- Mode of firing - reflecting firing rate and MV when applicable

An accurate management of such a data base, (in this case a Microsoft Exel Spreadsheet), was maintained. (Annexure L1).

The GA1, as seen in Annexure A, was instrumented using various types of transducers. The weapon, its interfacing structures and environment, were instrumented to obtain data reflecting a true representation of events (Figure 16).



A – Target: Dispersion & Accuracy; **a** – Target Location; **B** – Chronograph: Projectile Muzzle Velocity;
C – Strain Gauges: Cradle Input Load (Gun Recoil); **D** – LVDT: Yoke Movement;
E – LVDT: Feeder Slide Movement; **F** & **G** – LASER: Breech Assembly Movement;
F & **G** – LASER: Recoil Spring Retainer Movement; **H** – Strain Gauge: Breech Buffer Nut Loading;
I – Load Cell: Structure Recoil Loading; **J** – Solenoid: Trigger Sensing;
K – Load Cells: Structure Loading; **L** – LVDT: Barrel and Receiver Bush Movement;
M – Piezo Electric Sensor: Barrel Discharge Pressure Profiles; **N** – LVDT Breech Movement

Figure 16: GA1 Identification of Test Sensors

It should be noted that the capturing of real time data contributed to not only a better understanding of the behaviour of the weapon and its components, it also provided information which was essential to verify and calibrate future simulation models.

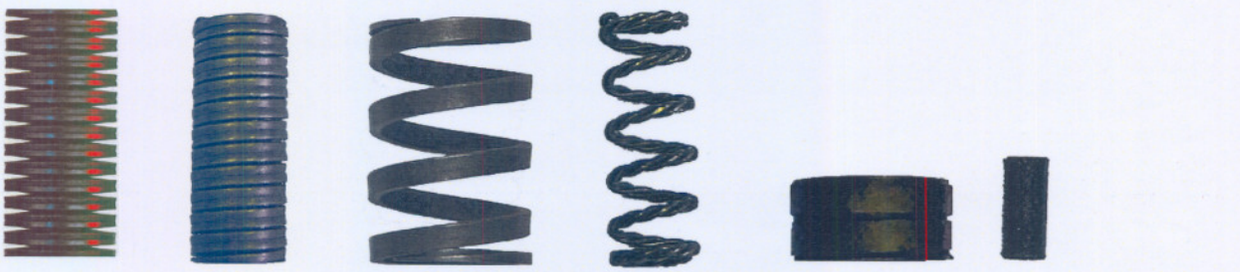
Table 1 summarized all the measurements taken, which provided enough information to model the motion behaviour of the weapon.

Table 1: GA1 Instrumentation Cross Reference Table

SYSTEM IDENTIFICATION	PARAMETER	TRANSDUCERS
Barrel Group *Reference:* *Figure 8*	Barrel movement (see also Receiver Group)	LVDT
Feed Housing Cover Group *Reference:* *Figure 11*	Feeder slide assembly movement	LVDT
Feed Housing Cover Group *Reference:* *Figure 11*	Trigger sensing	Sensing: Solenoid Switch Activation
Feed Housing Recoil Group *Reference:* *Figure 12*	Recoil spring retainer movement (see also Breech Assembly)	LVDT & LASER
Receiver Group *Reference:* *Figure 13*	Receiver bushing movement (see also Barrel Group)	LVDT
Receiver Group *Reference:* *Figure 13*	Casing structural loadings	Strain Gauges
Receiver Group *Reference:* *Figure 13*	Breech buffer housing nut recoil loading	Strain Gauges
Breech Assembly *Reference:* *Figure 14*	Breech movement	LASER & LVDT
Soft Mount	Cradle Yoke movement	LVDT
Soft Mount	Cradle - Soft Mount Input Load	Strain Gauges
Mounting Structure	Structural Loadings Weapon mounted in soft mount (Cradle)	Load Cells & Strain Gauges
Mounting Structure	Structural Loadings Weapon Rigidly mounted	Load Cells & Strain Gauges
Projectile	Muzzle velocity	Chronograph
Target	Dispersion & Accuracy	Target Template & Projectile colour coding
Blasting Pressure Profiles	Barrel discharge pressure profiles	Piezo Electric Blasting Probes & Visual sign in soft sand - Camera

A good example of the instrumentation required to measure behaviour, is that applied to the wide variety of springs and dampers that were included in the system. Some of these are shown in Figure 17 and are presently used within the GA1 weapon system. Combinations of all these springs were available during the development of the GAMA.

For example, the coil spring with its various cross sectional shapes and sizes, plays a major role in the dynamical behaviour of a weapon system. This must be differentiated from multi-stranded springs, disc springs, friction springs, polyurethane elastomers sections and the implementation of variable orifice pressurised damper actuators and buffers. Measurements taken must be sufficient to fully describe a component's individual behaviour within the system, as it needs to be formulated correctly within the simulation packages.



Disc springs (Stacked) [030][031] | Continuous Disc Spring Pack | Helical Coil Spring (Square Section) [032] | Multi-Stranded Helical Coil Spring [033] | Friction Springs Ringfeders [034] | Fibroflex Springs/Spacers Polyurethane Elastomers [035]

Figure 17: Various Spring Types

It is important to ensure that all data acquisition measuring equipment has adequate capacity for sensing the intended behaviour. Besides the sampling frequency of the data acquisition system and channel saturation, the frequency response of all the equipment used must be adequate to ensure that no data is lost.

The sampling frequency of the data acquisition system was set as high as possible after which raw data was subjected to the necessary filtering.

Constraints for filtering data channels are greatly dependent on the purpose for which the data is to be used. An example for filtering is as follows:-

*Raw data filtered with a pre-designed KLPass Filter (Kaiser Low Pass FIR Filter Design - Cut off Freq. (F_C) =120 Hz; Stop Band Edge = 125 Hz, Stop Band Attenuation. = 40 dB, Sampling Rate 4.065 kHz.). Fc being based on the average weapon operating frequency:- Fc. = ($1/t_{tot\ cycle}$) *10 or the shortest rise time measure during a tests:- Fc = 1/ ($t_{rise\ time}$ * 0.25)]*

Transducer frequency response inadequacy can cause the capture of incorrect data. An example of this occurred when the breech movement was firstly captured using an inductive type Linear Voltage Differential Transducer (LVDT) with an undesirable frequency response. Results indicated that the frequency response was too low. Due to the displacement rate change, i.e. velocity and accelerations during turn around time, the inductive field strength did not collapse rapidly enough. Besides incorrect total travel measurements, displacement readings were not a true representation of the breech turn around motion during breech buffer contact and breech at chamber lock position. The use of LASER technology was introduced as an overlay to the LVDT data. The maximum travel with the existing Lasers was 20 mm. This solved the problem and resulted in the capture of the correct data.

Cognisance of any phase shift between recorded channels was also being taken, especially when exploration of weapon behaviour was examined by overlaying recorded channels. Normally these phase shift between channels can be related to sampling procedure of the data acquisition equipment. However, the equipment used during the firing trials made use of a *sample-and-hold* instead of *channel sweep.* This prevented any relative phase shifts between recorded channels.

The launching of the projectile and the simultaneous initiation of motion of the barrel, are directly related to the pressure build-up in the chamber due to the burning propellant.

$$BurningRate = \frac{ds}{dt} = BP^a \qquad [036]$$

s = Reduction in size of the granule
t = Time in seconds
B = Burning rate of the propellant composition
P = Gas pressure in the region of the granule
a = The pressure index of the propellant composition

The projectile is driven along the rifling of the barrel by the expanding gasses simultaneously forcing the barrel and its interfacing components rearwards, as predicted by Newton's laws for motion.

Simulating the detail of the aforementioned phenomena would increase the complexity of the model. However, by simply measuring the motion of the barrel and the breech assembly, the calibration of a motion model was possible with a much reduced complexity. In this way the discharged pressures due to the burning rate of the propellant and the uncontrolled leakages of the expanding gasses between the projectile driving band and barrel rifling, could be incorporated into the model indirectly but effectively.

The barrel motion was obtained using a LVDT. The cycling of the barrel is directly related to the ammunition being fired. The amplitude vs. time of the barrel motion was one of the key factors for calibration of the simulation model. This motion of the barrel is the main cycling driver for the simulation of the hardware during each firing cycle.

In Figure 18, the FEA results on the receiver casing rear end indicated the best position for the application of the Rosette Strain Gauge for motion

model calibration purposes. Initially a unit load of 1 Newton was applied to determine the best location for the strain gauges.

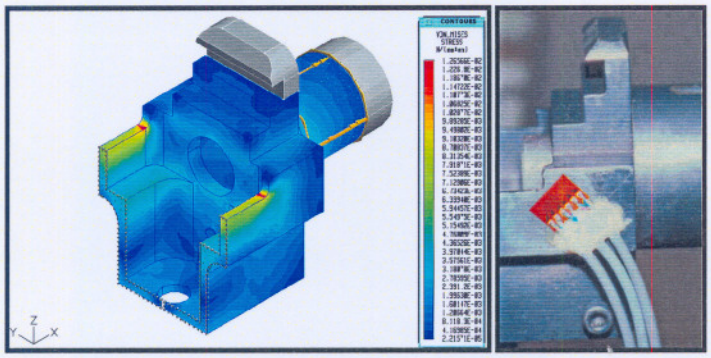


Figure 18: Receiver's Strain Gauge Position

Real time strain measurements during firing were used to calculate stresses.

$$\varepsilon_{max}, \varepsilon_{min} = \frac{\varepsilon_1 + \varepsilon_3}{2} \pm \frac{1}{\sqrt{2}}[(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_1 - \varepsilon_2)^2]^{0.5}$$

$$\sigma_{max}, \sigma_{min} = \frac{E(\varepsilon_1 + \varepsilon_3)}{2(1-\mu)} \pm \frac{E}{\sqrt{2}(1+\mu)}[(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_1 - \varepsilon_2)^2]^{0.5} \quad [037]$$

ε = Strain

E = Young's Modulus of Elasticity in Pascal

μ = Poisson's Ratio

σ = Stress in Pascal

Stress measurements were not only used for the verification of motion and structural simulation models, but were also used as a design parameter, which have to be taken into consideration when safety related issues are addressed during weapon design.

Ninety degrees (90°) rosette strain gauges were applied to the recoil buffer housing nut and the cradle yoke. The orientation and connectivity of the active gauges, as seen in Figure 19, allows for the measurement of compressive and tension loading outputs while eliminating the effect of temperature, bending and torsion (Annexure J). [038] [039] [040] [041]

$$\varepsilon = \varepsilon_n = \frac{1}{2(1+\mu)} \cdot \frac{4}{k} \cdot \frac{U_A}{U_E} \quad \text{and} \quad \varepsilon = \frac{P}{AE} \qquad [042]$$

$$E = \frac{\sigma}{\varepsilon} \quad \text{and} \quad \sigma = \frac{F}{A} \qquad [043]$$

ε = Strain (Active Strain Gauges: R_1, R_2, R_3, R_4)

σ = Stress in Pa

μ = Poisson's Ratio

k = Gauge factor of strain gauge

U_A = Output Voltage of Wheatstone Bridge in Volts

U_E = Excitation Voltage of Wheatstone Bridge in Volts

E = Young's Modulus of Elasticity in Pascal

A = Area in square metres

P = Pressure in Pascal

F = Load in Newton

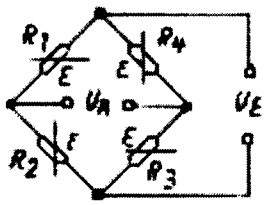


Figure 19: Wheatstone Bridge Configuration

Besides the traditional way of setting up the data-acquisition system, all transducers together with the self instrumented recoil buffer housing nut and cradle yoke, were subjected to an absolute calibration check procedure. Strain indicator boxes are traditionally utilised to represent transducers during the calibration of the data acquisition system.

The strain indicator was used to set-up / calibrates data capturing equipment especially over long distances. Accuracy was ensured by signalling a predefined transducer output with the strain indicator, whilst the capturing equipment was set to measure the precise reading. Data was captured by adjusting the output from the strain box to represent the normal transducer output between zero and full scale. The absolute calibration of sensors was also conducted.

During the absolute calibration checks, amplifiers gain settings were verified for correctness. Verification was achieved by subjecting all sensor / transducers to a predefined known input, typically shown in Figure 20, while reading the outputs. The outputs were plotted while the inputs were incrementally changed.

The individual loading of the recoil buffer housing nut and cradle yoke was accomplished using a hydraulic actuator in series with the referenced load cell. The nut represents the buffer output force and the yoke, the cradle input force. Two data channels were monitored, the reference load cell and "new manufactured load cell" respectively. The amplifier calibration settings for both the channels can be calculated as follows:-

$$FS = U_A = U_E \cdot Gain \cdot LoadCellSensitivity \qquad [044]$$

FS	= *Required Full Scale Reading within the Capacity of Load Cell*
U_A	= *Amplifier Full Scale Output sensing Load Cell in Volts*
U_E	= Excitation Voltage from Amplifier to Load Cell
Gain	= *Amplifier Gain Setting*
LoadCellSensitivity	= *Load Cell's Design Sensitivity [mV/V]*
	(Normally Load Cell sensitivity is $2x10^{-3}$ Volts Output / Volts Input)

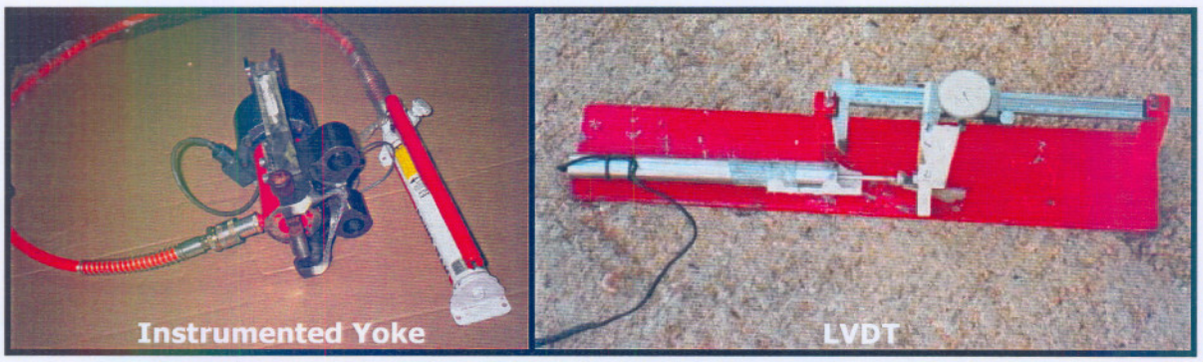


Figure 20: Typical Calibration Checks of Transducers

On completion of the loaded and unloaded cycle, the results were subjected to a linear curve fit simultaneously requesting a regression of this data. The curve fit equation through the output data will give the relevant calibration.

The calibration equation's regression was only accepted for use when fits were as close as possible to 100%. Similarly, LVDT's and LASERS were also verified.

A further check was to perform a dynamic dry cycling cycle test where all data channels were verified.

The live firing tests were then performed according to a fixed firing test procedure covering single shot, snap shot and bursts firing.

3.4 Results

Captured data was examined using DADISP signal processing software and MATLAB. An analysis of the data captured during live firing tests revealed the following results, while 20x82 mm PRAC ammunition was used. [045]

Ignition @ 0.0 ms (Start)

Time to reach Max Breech Travel	= 34 ms
Max Breech Travel	= 297.7 mm
Max Buffer Compression	= 7.7 mm
Max Buffer Recoil Force	= 18.504 kN
Time for Breech to reach Sear Position	= 37 ms (279 mm)
Max Barrel Recoil	= 23 mm
Time for Breech to reach Barrel Chamber	= 82 ms
Rate of Fire	= 732 rpm(Breech Total Cycle Time 0.082 sec.)

The stress measurements on the receiver were:-

Von Mises Stress	= 109.7 MPa
Max Principal Stress	= 116.9 MPa
Max Shear Stress	= 50.27 MPa.

The chronograph revealed an average muzzle velocity, for the GA1 firing 20x82 mm ammunition, of 720 m/s.

Although the weapon is known to be an area weapon, target data (Figure 21) was obtained for reference purposes. These results could be used to compare dispersion and Mean Point of Impact (MPI) measurements with the new design that was to follow.

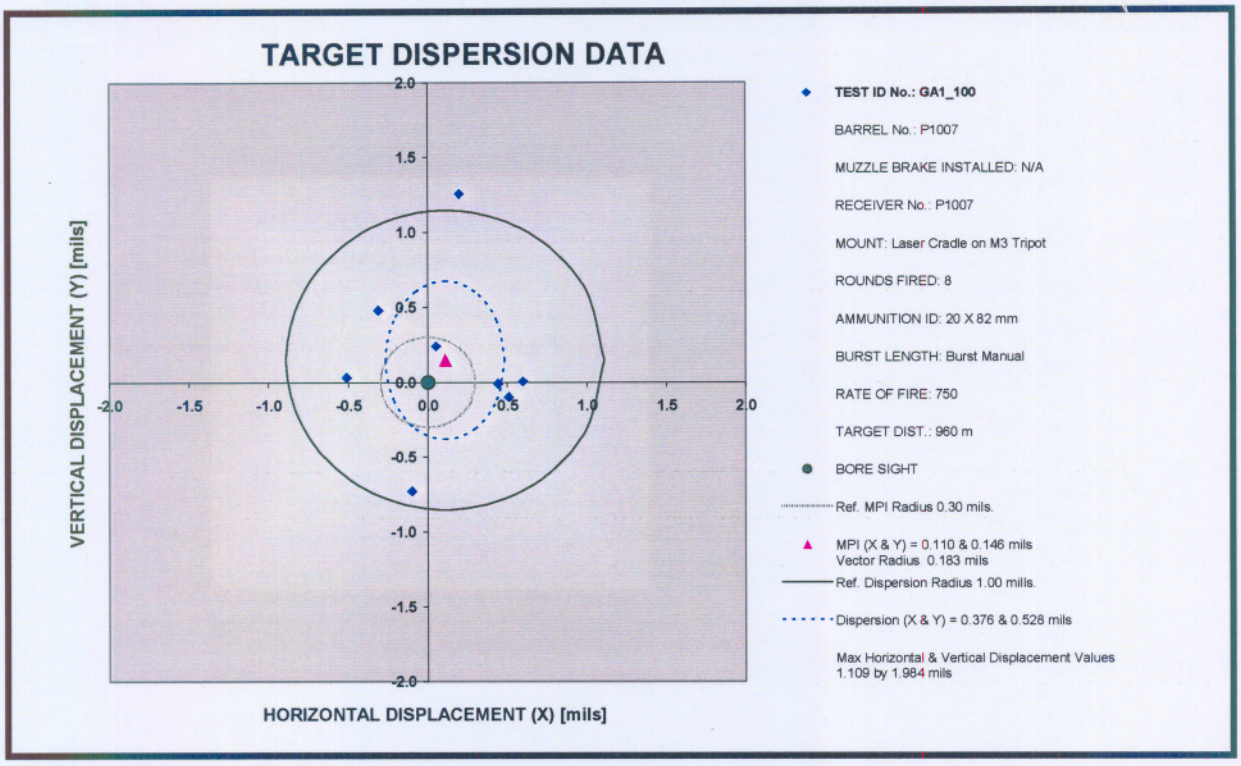


Figure 21: GA1 Target Data

Although the structural behaviour of a weapon influences that weapon's performance with respect to its dispersion and accuracy, (especially when firing a burst), the barrel condition near the end of its life cycle also influences this performance. To establish a barrel's behavioural pattern, projectiles were colour coded to determine the sequential impact on the target during firing.

Yawing of a projectile during launch not only influences the flight time of the projectile due to drag, but has an effect on the terminal accuracy of the

weapon itself. Yawing patterns, if any, are normally measured at a distance of seven meters using a template overlay (Figure 22). No yawing was, however, evident during the characterising phase of the GA1 weapon system.

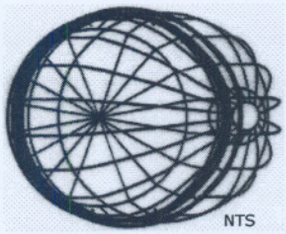


Figure 22: Typical Yawing template for 7°

The blasting profile of the GA1 weapon was also measured using a predefined grid around the weapon (Figure 23). This information was a supplement to the dynamic and structural measurements, as it would only be used to evaluate the environmental impact of the weapon when comparing it to the subsequent GAMA design become necessary.

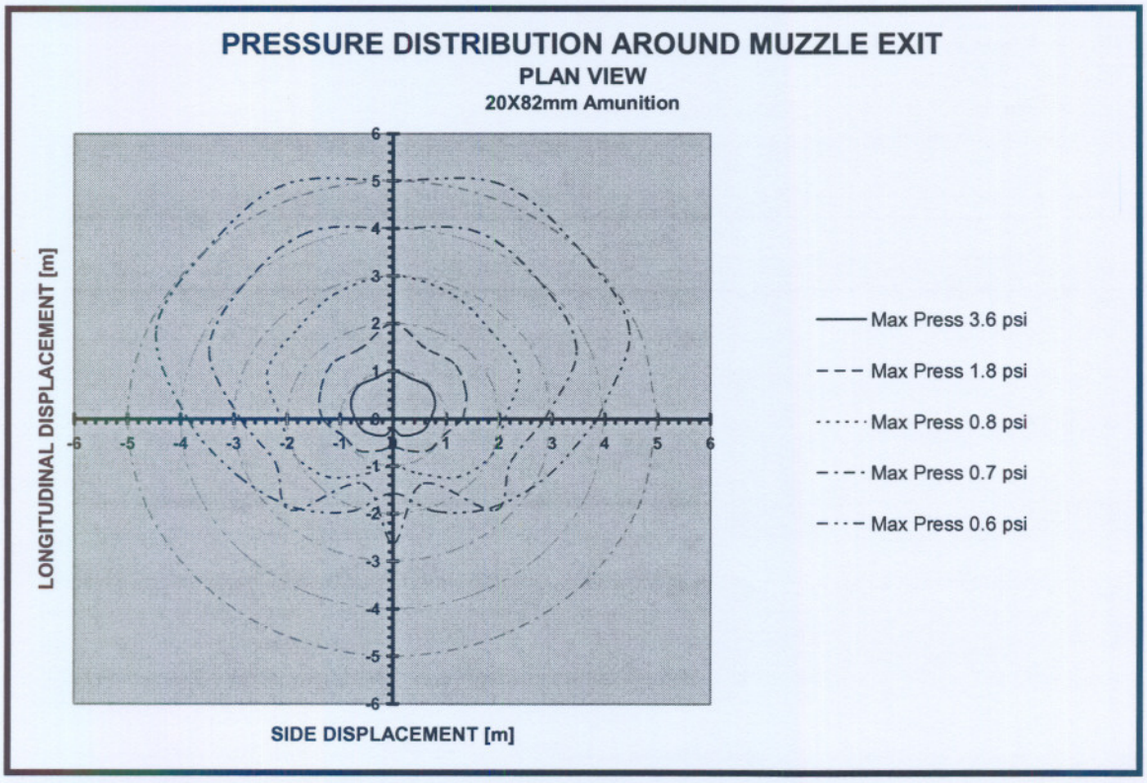


Figure 23: Blasting Profile of the GA1 Mounted on a M3 Tripod

The peak sound pressure levels were also calculated using the following equation -

$$L_p = 10Log\frac{P^2}{p_0^2} \text{ dB} \qquad P_o = 20\ \mu Pa \qquad [046]$$

3.5 Conclusion

Many tests were performed and various methods used to obtain data (Figure 24). Cross correlation between these tests results proved to be useful during simulation.

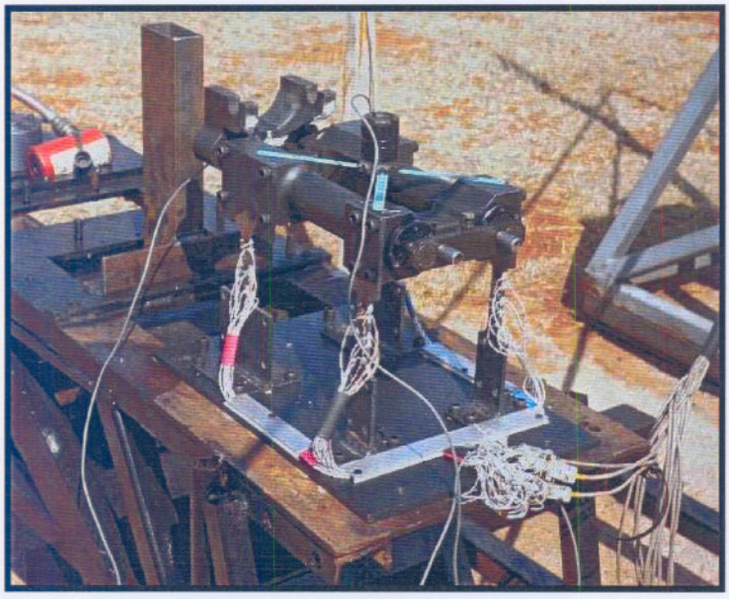


Figure 24: Test Setup to Measure Recoil Force in X-Y-Z Directions

From time to time retests were performed to verify certain scenarios that were required by the simulation process. These also confirmed that the data used in the model was reliable.

CHAPTER 4 SIMULATING THE BASELINE WEAPON SYSTEM

The base line weapon system was simulated using structural and dynamic simulation packages. As mentioned before, a full understanding of the hardware motion behaviour pattern of this weapon in the finest detail was essential before commencing with the generation of the simulation models. [047] [048]

4.1 Simulation Models

Virtual reality is the simulation of the weapon hardware within a defined environment.

The constraints for each component not only define the degrees of freedom encountered, but also relate to relative interfaces of components with each other. Interface definition was very important as it ensured that the correct sequential flow of events was catered for.

The simulation of the base line weapon laid the foundation for the development of the new rapid fire multi calibre weapon system. The proper definition of structural and motion models for the GA1 resulted in a reduction in time when developing GAMA later.

The weapon hardware was constructed using the latest 3D CAD software. Variable dimensions were effortlessly accommodated using the philosophy of parametric design. Automatic regeneration of the 3D CAD models was therefore possible when design changes were implemented. Inherent flaws, so frequently experienced during manual regeneration of models, are eliminated by utilising the automatic regeneration method within the CAD environment. During this process an appreciable saving in time was experienced.

Utilizing CAD, the weapon was drawn in intricate detail. This enabled both the analysis, as well as the later automatic production of components using existing CAD/CAM interfaces. Rapid prototyping of components was possible using Central Navigation Computer (CNC) Machines. This also allowed for any design changes that were still deemed to be necessary.

It should be noted that the data pack of the GA1 baseline weapon consisted only of paper and CPI drawings, due to the fact that CAD was not available at that time. It became evident that the development of a project such as GAMA, by means of simulation, would not be possible without a three dimensional data pack in an electronic format.

During the reproduction of this GA1 data pack, various checks were performed, and corrective action was instituted where necessary. Traditionally, it was acceptable to produce prototype hardware from a basic design. During a process of trial and error, test results were used to modify hardware until adequate results were obtained. This prototype hardware was then used as an input to generate and finalise the formal manufacturing data-pack. This does not necessarily mean that proper design calculations were not made, it only confirms the fact that the mathematical tools of today were not available then to do design refinements utilizing simulation software.

At times errors were unintentionally captured during the generation of the GA1 data-pack. Rectification of these was, however, possible, as discussed in Chapter 2.3. During the process of transposing data manually into electronic format, errors were picked up and rectified. This ensured a high integrity of design. The data-pack formed the basis of the simulation process which progressively advanced from the GA1 stage through to GAMA. Using this accredited electronic data-pack, queries such as Centre of Gravity (COG) position, inertia's, mass and geometry details could now easily be obtained.

Throughout the development process, electronic queries were frequently used to:-

- Verify hardware against CAD models.
- Facilitate the calculation and the implementation of environmental constraints within the FEA and Motion Analysis (MA) design phase.

The formal release of the 3D CAD data pack was only effected after meticulous checks against the existing hardware and the paper/CPI data-pack were carried out. On completion, the electronic data pack was exported to the FEA and MA software packages.

Using 3D CAD geometry (Figure 25), mass -, material - and geometrical properties were automatically conveyed to the simulation software as an integral part of the transferring process. Besides analysing major / critical components, FEA and MA results were used to identify the need for analysing additional interfacing components.

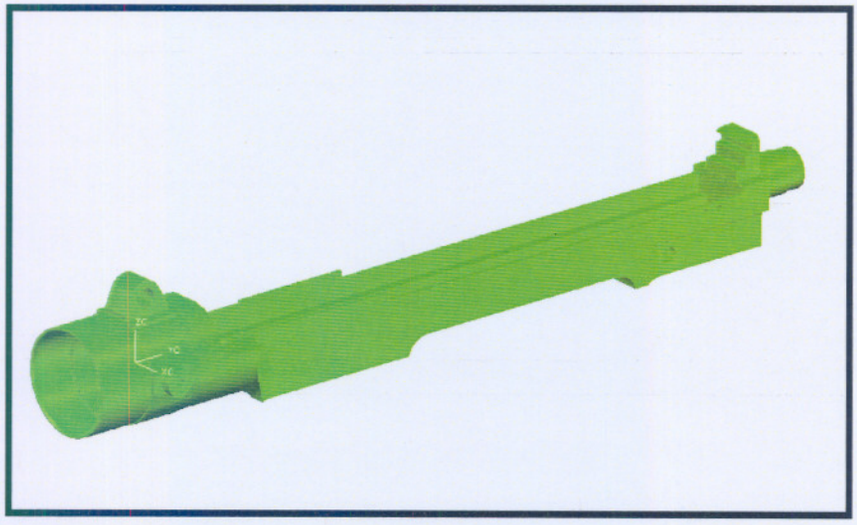


Figure 25: 3D CAD Model of the GA1 Receiver

Simulation models sometime ran continuously for a week before results were obtained. Since the science and practice of simulation was not as advanced then as it is today, the physical test results that were obtained were used to verify and calibrate the simulation models.

Although both structural and motion simulations were used, this was limited to defining the ultimate environmental constraints. Simulating the total weapon's motion behaviour was only possible by breaking it up into various phases.

Each module represented a specific phase in the total firing cycle of the weapon. Checkpoints in the models were introduced to ensure numerical stability. It was not possible to set up a motion model that could run continuously throughout the firing cycle. The initial conditions for each consecutive phase were therefore defined from data obtained from the previous phase. Test data was also used extensively to verify the definition and the initiation of each consecutive phase.

4.1.1 Structural Analysis

The processes involved in FEA are repetitive, and for this reason only the circumstances surrounding special cases arising out of the development will be emphasised in this thesis.

Although the intrinsic detail incorporated in CAD is necessary for manufacturing, it is not always essential for the analytical process. It is therefore at times important to suppress trivial details since these generally only serve to increase the complexity of the analysis, without having any real effect on the results being obtained. A typical example is the chamfering of the outer edges of the receiver, which serves to improve its geometrical appearance and also prevents possible injury to personnel. Such trivia are not important for analysis purposes.

On the other hand, sharp edges and corners could result in stress concentration which needed to be explored and properly analysed. Examples of this are the interfacing comparties on the barrel, receiver bushing and

breech bolt head. These needed to be analysed for stress concentration areas due to their interfacing role in containing the rapid increase in barrel chamber pressures due to the burning propellant.

The complexities of the models were increased or decreased dependant on the intrinsic detail that was included or omitted. This was an iterative process that was based on the experience of the author and served to fast-track the process.

In addition, the complexity of detail within CAD models is also directly related to the size of the elements and the quantities of nodes used per element. The total number of nodes, and the degrees of freedom of each node, dictated the size of the simulation model. (CPU time consumed for analysis is directly related to the size of the model).

FEA consists of Pre-processing, Analysis and Post-processing. Pre-Processing is the preparation of the model and Post Processing is the exploration of the results in various formats. Figure 26 illustrates all the basic tasks identified by the author to be performed during the FEA process.

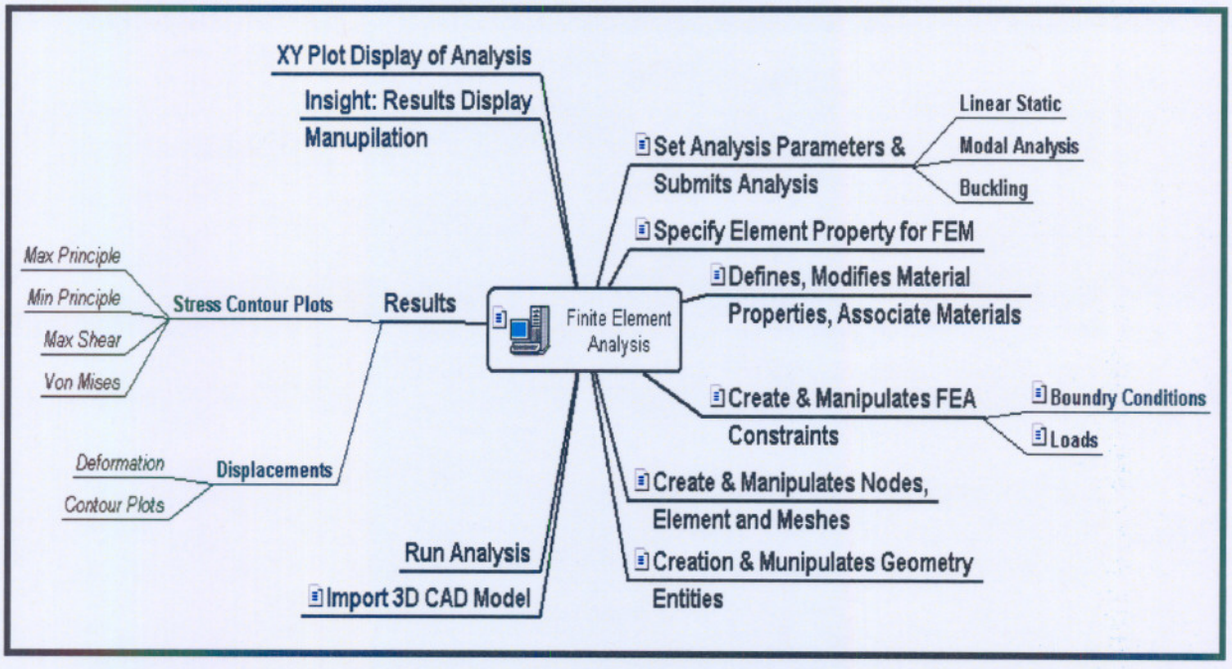


Figure 26: Graphical Representation of the FEA Process

Initially the CAD model geometry has to be properly prepared and manipulated. This is followed by meshing the geometry manually or automatically, using various types of elements. A brief description of the different types of elements available can be found in Annexure F. Sometimes it is necessary to use a combination of these elements together to achieve a proper representation of the CAD model.

Overlaying nodes are merged in a proper manner to ensure that continuity is correctly managed. The technique of constraining the model at various surface and edge nodes was employed to ensure that the behavioural pattern of hardware was correctly simulated. Partial simulation was also an option when the designs were symmetrical. This made it possible to reduce the size of the models being generated.

Although the existing weapon was a fully qualified weapon system, analysis of all the critical components was essential, as stresses within these components were to be used as a reference during the subsequent development of the GAMA. During the FEA, special care was taken when modelling the barrel, receiver bushing, breech bolt head and the receiver.

Before any analysis could commence, it was necessary to obtain crucial 20x82 mm ammunition pressure test data from PMP (Annexure H). This is the pressure that is generated by the burning propellant during the firing of the rounds, as measured against time. (Ammunition pressures and muzzle velocities are normally measured during the commissioning of ammunition).

The projectile's dynamic behaviour, together with the pressure inside the barrel, are presented as a function of time in Figure 27A and displacement in Figure 27B. [049]

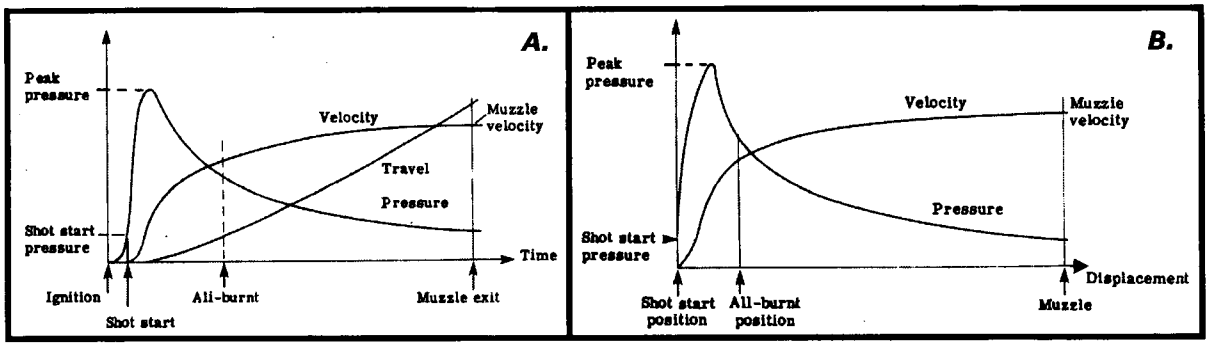


Figure 27: Typical Graphical Presentations of Internal Ballistic Results

The friction force that results from the rifling along the barrel on the driving band of the projectile, is also graphically presented in Figure 28.

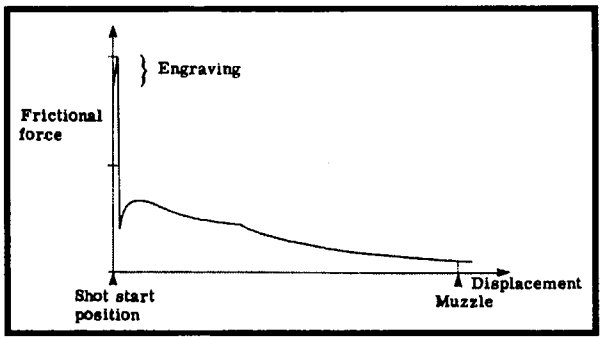


Figure 28: Typical Friction Force During Firing

The *proof pressure profile*, which is obtained when firing high pressure rounds, is used as a design driver when analysing the structural and dynamic behaviour of the weapon with respect to safety. The *standard ammunition pressure profile*, on the other hand, is used to characterize the normal dynamic behaviour of the weapon.

Utilizing the aforementioned internal ballistic theory, the pressure distribution along the barrel can be conservatively calculated as follows:-

$$P_A = P_C\left[1 - \frac{W_C}{2W_P - W_C}\left(\frac{S_A}{S_B}\right)^2\right] \qquad [050]$$

P_A = *Pressure at point A of bore [Pa]*

P_C = *Chamber pressure [Pa]*

W_C = Weight of propellant charge [kg]

W_P = *Weight of projectile*

S_A = *Distance from breech of equivalent chamber to point A*

S_B = *Distance from breech of equivalent chamber to base of projectile*

A more precise method of computing the internal ballistic behaviour of armament is also covered in the *Rheinmetall Handbook on Weaponry*. [026] The pressure distribution along the barrel is calculated as a function of the pressure generated by the burning propellant and the projectile's dynamic behaviour inside the barrel.

An LIW internal report predicts the internal –, intermediate - and external ballistic behaviours of projectiles. The author used the internal ballistic programme module of this report to calculate the projectile dynamics together with the pressure distribution profiles inside the barrel [051] [052]

This verified programme automated the calculating process for small to medium calibre weapons. The program is initiated through the reading of an input file, while the results are captured in an output file.

The input file, Annexure I, contained typically the following barrel and ammunition information:-

- Projectile Mass [kg]
- Projectile Mass moment of inertia - I_{ZZ} [kg m^2]
- Charge Mass [kg]
- Bore Diameter [m]
- Shot Travel [m]
- Rifling Angle (along the shot travel) [°]
- Coefficient of friction
- P_t - Chamber Pressure against Time [Pa]

The output data, Annexure I, could be manipulated and presented in various XY-Plots. During the GAMA development the two most important plots used were:-

- Projectile's pressure along the length of the barrel
- Projectile's velocity along the length of the barrel

A polynomial fit was used to smooth the results obtained for the shot travel along the barrel and the maximum pressure was applied to the barrel chamber.

During FEA, the forces and pressures profiles used are based on *maximum proof pressures* that can be encountered at any time, which is also a property of the high pressure ammunition (proof ammunition) that was used.

Before a system is certified as safe for use, the firing of high pressure proof rounds is compulsory. Proof ammunition is a major design variable and pressures profiles are therefore specified.

These pressure profile (Figure 29) are entered into the FEA model as a design driver for the barrel. Results are used to determine the minimum required wall thickness of the barrel. The total barrel design, with the inclusion of muzzle brakes and supportive interface structures, must be used when evaluating the barrel frequency.

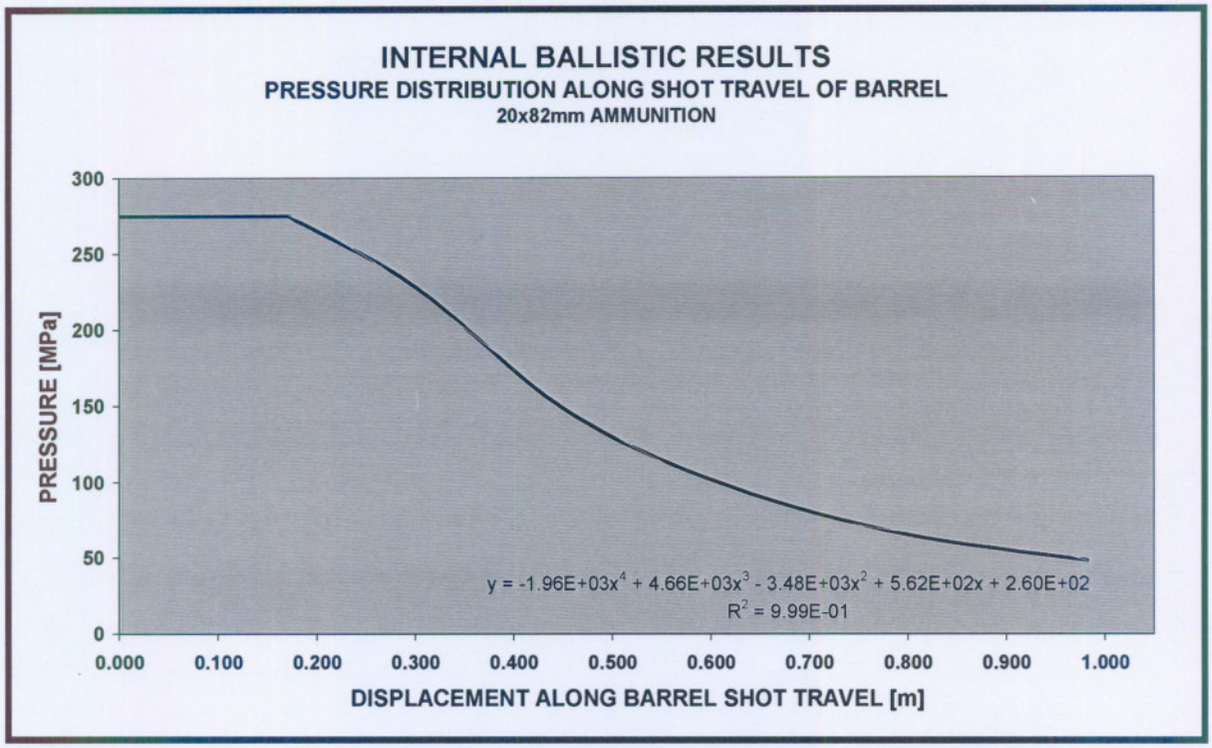


Figure 29: Internal Pressure Distribution Inside the 20x82 mm Barrel

The maximum chambers pressure was also applied to the bolt head bullet face, while constraining the translational and rotational movement of the bolt (Figure 30). These constrains are a true representation of the environment in which it operates.

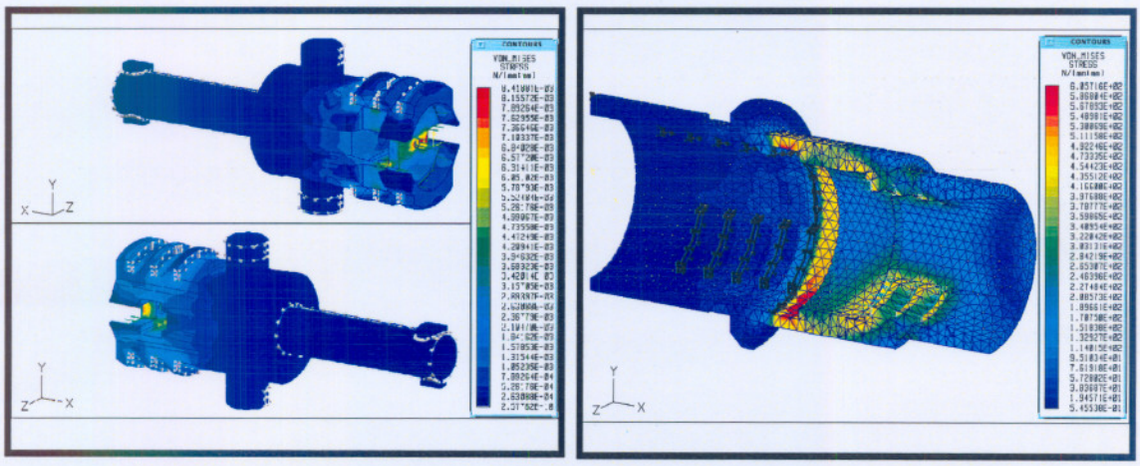


Figure 30: FEA Results on the Breech Bolt Head and Receiver Bushing

The receiver bushing was analysed in the same manner, by applying a uniform pressure along the breech bolt interfacing comparties area while constraining its movement at the barrel interfacing comparties.

4.1.2 Motion Analysis

MA was performed in parallel with FEA. The motion results obtained represented the dynamic behaviour of the weapon. This had an impact on the forces being induced in the weapon structure and affected the FEA. The interactive, but independent, usage of FEA and MA software resulted in the overall evaluation of the GA1 weapon (Figure 31).

The use of Mechanica software (since Adams was not yet available at the time), allowed the author to analyse the total motion behaviour of the weapon as rigid bodies interacting with each other. However, although this was a close approximation, it did not cater for the flexibility of the structures. Therefore correlation checks with physical measurements were carried out to improve the integrity of the simulation models.

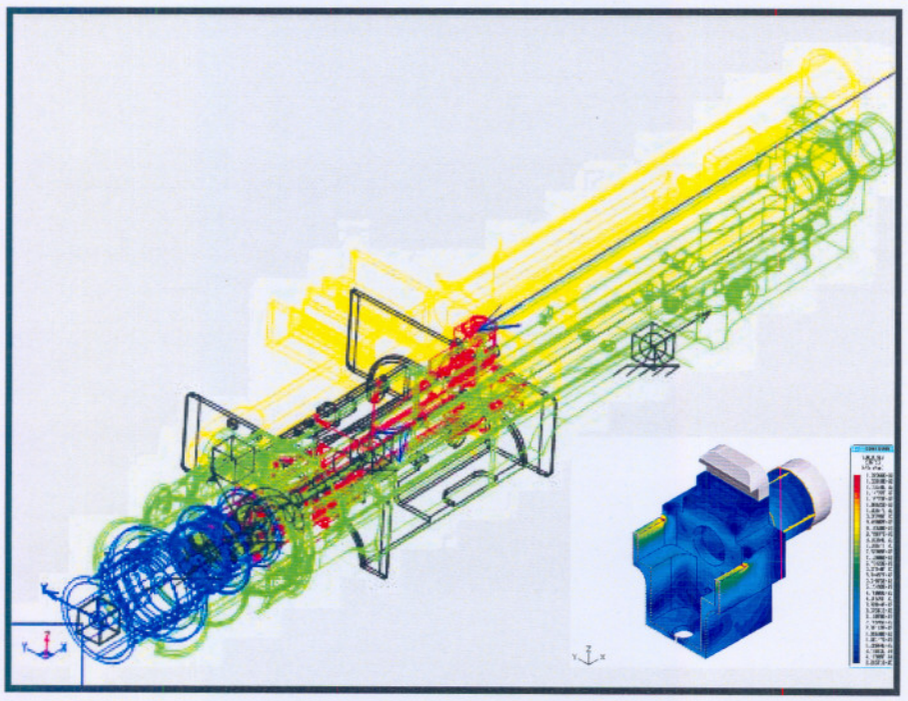


Figure 31: Motion Analysis and FEA used Interactively

Although a geometry generation interface is provided with most motion simulation packages, the option of rather importing the CAD models was chosen. All components were imported and displayed as wire-frame structures within the motion analysis package. Care was taken to ensure that the reference coordinate system coincided with the generated CAD model.

Components were also grouped into various defined layers within the motion simulation package, to facilitate the assembly of the model (Annexure G1).

The use of such layers, (which can be activated or deactivated), speeded up the development of GAMA, in that structures and components could be replaced or altered frequently. The mass and inertia properties were entered manually onto the Centre of Gravity (COG) point of each component.

Additional user defined points and markers on components and environmental structures were also used to define the motion behaviour of the weapon. Two dimensional curves were used as an overlay to obtain three dimensional movements relative to the various components and the environmental structures.

The motion models were initiated by driving the breech backwards with a force which is representative of the pressure available as a result of the burning propellant. All forces representing the chamber pressure, springs, buffers and dampers were applied to user defined points on the various components and environmental structures of the model (Annexure G2).

Today, the importing of solid bodies into Adams, enables the Adams Flex module to analyse the motion behaviour of a weapon while taking structural behaviour into account. Structural behaviour under dynamic loadings now forms an integral part of the motion solution. It also provides numerous improvements towards the definition of models with respect to the inter-connectivity of components, within a three dimensional environment. The

usage of structural edges and surfaces together with free body movement form part of the solution toolbox for motion analysis (Annexure G3). Unfortunately, this tool was not available during this project.

Time consumption is very important during simulation. The importation of 3D components, in order to visualise surfaces, is a feature that can consume a lot of memory, resulting in lengthening the analytical process.

Computational power is not only used by the solver, but is also required to update the models graphical appearance in so far as each time step is concerned. The regenerating of graphics should therefore be suppressed until the run is accomplished, in order to reduce the analytical process time.

Since the GA1 was already an operational weapon, no design effort was put into optimizing it. The focus was primarily on the compilation of simulation models to launch the development of the GAMA. The availability of these software packages provided the designer with the opportunity to optimise the GA1, but the development of new GAMA as a replacement for the GA1 took precedence.

During motion analysis, the main objective was to calibrate the dynamic behaviour of the weapon against the physical hardware performance. Only when this behavioural pattern coincided with the hardware behaviour, could it be said that the motion models were a true representation for the development of GAMA.

The main objective was therefore to produce a simulation model, with a reduction in complexity providing easy access and alteration capabilities for developmental purposes, while still representing the hardware performance in its present format. Simulation results proved to be closely related to the hardware performance.

4.2 Simulation Results

The following simulation results were extracted from the GA1 model firing 20x82 mm Ammunition. [045]

- Ignition @ 0.0 ms (Starting Reference)
- Tme to reach Max Breech Travel = 33 ms
- Max Breech Travel = 297.9 mm
- Max Buffer Compression = 7.9 mm
- Max Buffer Recoil Force = 18.442 kN
- Time for Breech to reach sear = 36 ms (279 mm)
- Max Barrel Recoil = 25 mm
- Rate of Fire = 732 rpm
- Time for Bolt to reach Chamber = 60 ms - 51 mm
  (Theoretical check - No stripping of a new round thus no Inertia & Stripping force)

The FEA Von Mises stresses were:-

- Receiver = 104 MPa
- Receiver Bushing $_{(20x82\ mm)}$ = 236 MPa

Preliminary theoretical hand calculation was performed on the receiver bushing centre section firing 20x82 mm ammunition-:

- Receiver Bushing $_{(20x82\ mm)}$ = 237 MPa

4.3 Comparing Test and Simulation Results

When comparing the test and simulated results the following minimum deviations were acknowledged:-

Primary parameters

- Ignition @ 0.0 ms (Starting Reference)
- Rate of Fire = 0.0% Goal
- Time to reach Max Breech Travel = 2.9%
- Max Breech Travel = 0.07%
- Max Buffer Compression = 2.6%
- Max Buffer Recoil Force = 0.3%
- Time for Breech to reach sear = 2.7%

Secondary parameter

- Max Barrel Recoil = 8.7%
- Von Mises Stress in Receiver = 5.2%

Primary parameters were used to calibrate and evaluate the motion models. Acceptance to proceed with the development of the GAMA was promulgated by the author when acceptable correlations between measured and simulated results were noted. [037]

CHAPTER 5 DEVELOPMENT OF THE NEW WEAPON SYSTEM

5.1 Requirements of the New Weapon System

The verified GA1 simulation models as described in Chapter 4, were now used to develop the GAMA.

The specification of the new weapon was given in detail in Chapter 1. The reader is reminded that the primary and unique characteristic of this weapon was the ability to fire a specified range of ammunition, each having its own unique performance and geometrical properties, which included either percussion type or electrical type primers. [004]

The design of any weapon is not only dependent on its own internal requirements, but also of those of external interfacing platforms. These constraints represent often opposing requirements that need to be resolved by means of compromises. Without the aid of simulation, such trade-offs are extremely difficult.

For example, limiting the mass, recoil force, recoil displacement and acquiring a safe rapid firing multi calibre weapon conforming to tough performance criteria, was only possible by means of simulation. [013]

The design and performance requirement specifications for the GAMA were presented to ARMSCOR for approval. [053] [054] Although the GAMA was primarily developed for the SAAF new Light Utility Helicopter, it was felt that it should be able to interface with all existing GA1 platforms. The rationale behind this strategy was that this weapon had to replace the existing GA1 for the foreseeable future.

Due to the high costs of test range facilities, development hardware and ammunition, ARMSCOR agreed to supply facilities, ammunition, platforms

and old GA1 weapons as a standard Client Furnish Equipment (CFE). [055] [056]

5.2 Analysis and Design

Due to the fact that the simulation process in general is very repetitious, only prominent aspects are covered in this chapter.

The new requirements and constraints provided in the final specification dictated the design of GAMA with respect to its fit, form. Maximum recoil force, travel and overall mass were kept to a minimum, with the specified firing rate of the various types of rounds being the design driver.

The two major properties of the ammunition were:-

- Geometrical properties
- Performance properties

The overall length of the round dictated the ammunition feed interface of the weapon. The lower surface and rim of the cartridge case interfaced with the bolt head bullet face, the extractor and the ejector. The shape and size of the barrel chamber, together with the bolt's bullet face position, was determined by the cartridge case. This ensured that the head-space was correct as recommended by the ammunition manufacturer.

The correct head space for each type of round is a function of the ramming action of the round into the barrel chamber, after which the chamber is locked prior to ignition. This ramming of the round into the chamber results in the case being compressed into a predefined headspace, also known as case crush. The two important parameters are therefore headspace and firing pin protrusion.

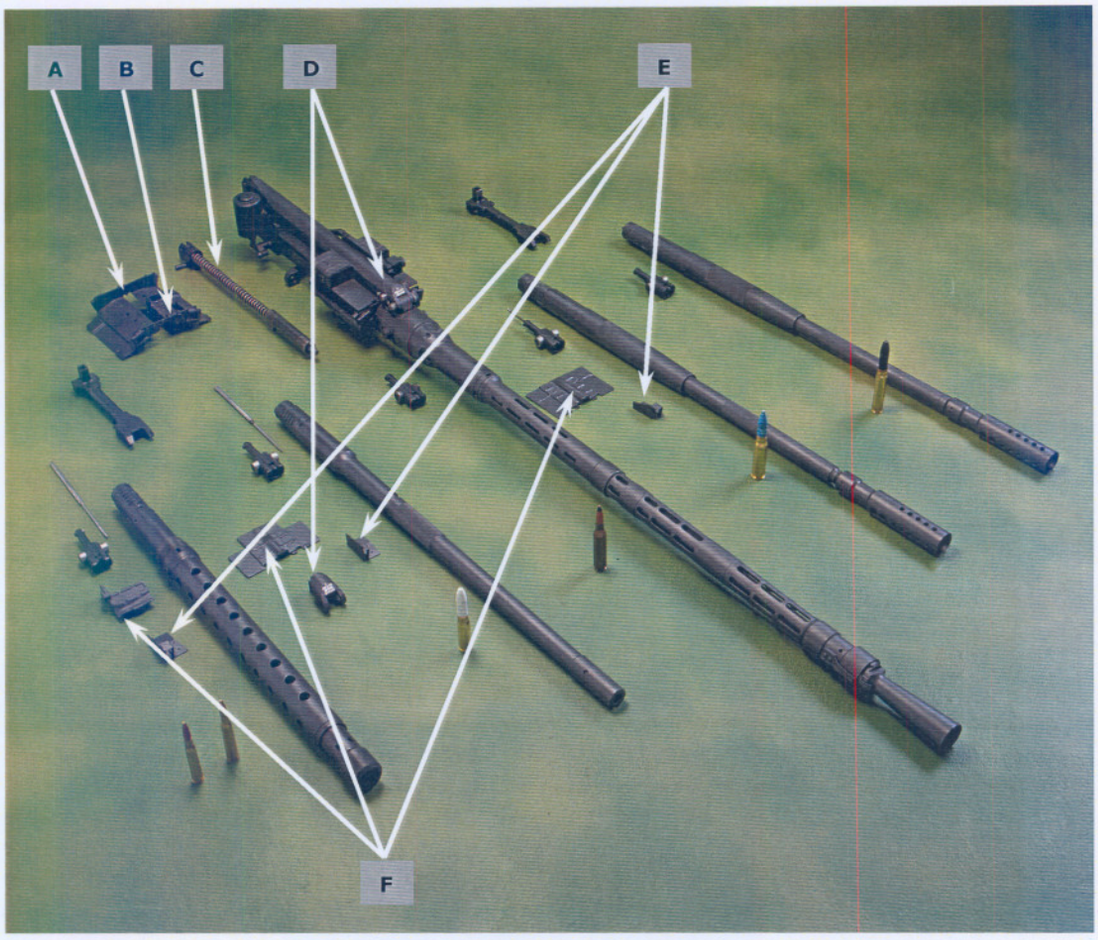
In order to comply with good configuration control, the GAMA project was registered to have a unique product code "747". The Master Record Index (MRI) with this product code reflects all design drawings, documentation, tooling etc. associated with the GAMA project. When GA1 MRI items were found to be compatible with the GAMA design, these items were included as standardised items, maintaining their original "376" product identification code. [057] Once simulation authenticated the design of a particular component, it was released for the compilation of drawings for manufacturing.

The longest round in the series (which was the 20x110 mm round) determined the total length (Geometrical Properties) of the weapon. This was therefore used as the starting point of the development of the GAMA. All the motion control parameters were based on the new absolute and relative positions of the breech bolt mechanism group, ammunition feed system group, recoil mechanism group, barrel group and the receiver group.

The Performance Properties of the weapon, however, were determined by the ammunition with the most severe pressure profile. This was the 20x102 mm round Consequently this dictated the development of the breech buffer, breech bolt mechanism group, receiver bushing, unlocking ring, barrels, springs, buffer and recoil mechanisms.

The whole range of the ammunition between these two extremes (geometry and pressure) could now be easily accommodated as well.

In order to design other support components, such as the feed tray, the cartridge stop, the cover hinge, spacers, and the cartridge ramp (see Figure 32) the use of simulation and/or motion analysis was not necessary. Basic calculations, good gut feel and engineering common sense, together with experimental methods, were used here.



A–Feed Tray **B**–Cartridge Case Stop **C**–Recoil Spring **D**–Cover Hinge **E**–Spacer **F**–Cartridge Ramp

Figure 32: GAMA Hardware Layout

Future expansion of GAMA with the incorporation of additional types of ammunition is possible utilising contemporary simulation packages (Annexure G3).

Recoil forces obtained from the simulation models enabled the design of a new composite buffer (Figure 33). In this design, the experimental data describing the motion of the breech bolt mechanism group within the receiver group, was matched with the simulated results (Annexure M1).

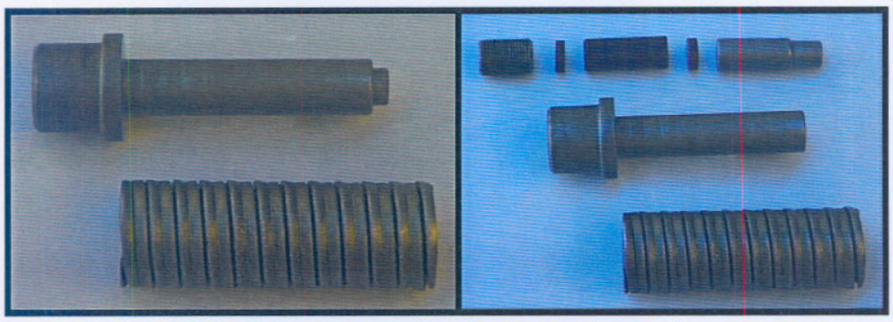


Figure 33: Composite Breech Buffer Assembly

The stress levels in the breech bolt head and receiver bushing of the GA1 locking configuration was of an unacceptable level when firing the new range of ammunition.

Simulation steered the design towards a novel concept whereby the locking of the chamber was accomplished by increasing the rotational angle of the breech bolt head inside the receiver bushing. In addition, an alternative material, capable of sustaining excessive loadings, was introduced.

The increase of the rotational angle of the breech bolt expanded the contact area, thus resulting in a reduction in the stress loadings. The conventional case hardened material was replaced by SK002 which was subjected to an Electro Slag Re-melting (ESR) process. (SK002 conforms to the GAMA's designed stress level requirements).

The increase in the rotational angle of the breech bolt head was achieved by introducing driving cam surfaces. A telescopic motion between the bolt head and bolt carrier resulted in a clockwise bolt head rotation and a 90° chamber locking configuration (Figure 34).

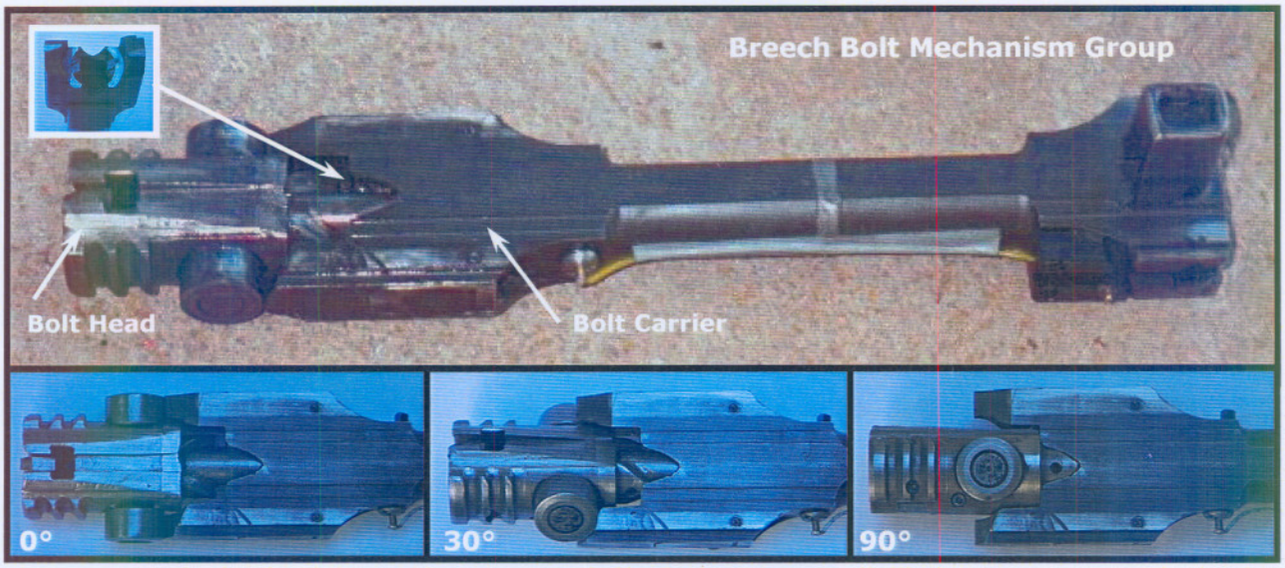


Figure 34: Rotary Motion of the Breech Bolt Head

Subsequently, improved cam surfaces on both the receiver bushing and the unlocking ring were introduced to cater for the increase in the breech bolt head's rotational angle (Figure 35).

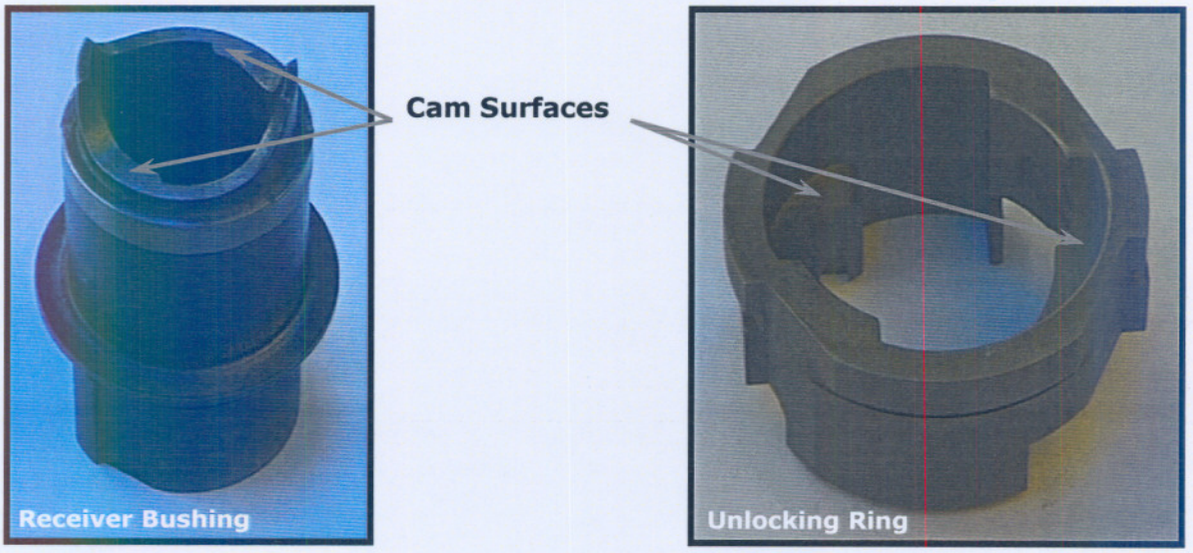


Figure 35: Receiver Bushing and Unlocking Ring

The cam surfaces on the unlocking ring were designed to drive the bolt head anti clockwise through 90°, opening the chamber, while sustaining the forces generated by the rearwards motion of the barrel, receiver bushing, and breech bolt mechanism group. In addition to the material change (SK002),

the contact area between the unlocking ring cam surfaces and the breech bolt head rollers were optimised to facilitate a reduction in loadings.

Up to this point, the use of percussion primed ammunition was described. However, the 20x102 mm ammunition is equipped with electrical type primers and therefore a new method of activating the ammunition was introduced. This enabled the GAMA to handle both types of ammunition.

The GAMA was fitted with an electrical circuit designed to control the weapon remotely from a weapon control console. A multi core harness was used as an interface between the weapon and its control console. The console was equipped with an Armament Master "ON-OFF" switch and a trigger. The trigger button dually control the 28 V DC supply to the trigger solenoid and 160 V DC electrical charge through to the electrical firing pin.

The detailed design interfaces for GAMA are summarised in an interface control document. [058]

The design of the electrical firing pin and the insulation between it and its surrounding structure during motion, proved to be a challenge. The CSIR was approached to assist in this matter. They suggested a ceramic coating process that has excellent wear resistance and dielectrical strength capabilities. This coating was applied using a Metco Flame Spray Process. [059]

Unfortunately, the impact loadings between the firing pin and the primer caused the ceramic coating to fail in the vicinity of the bullet face. The damaged insulation caused an intermittent short circuit between live and ground. This problem was resolved when a special mould was designed for the firing pin, coating it with a mixture of Ureol 6414A & Ureol 5117B (Figure 36).

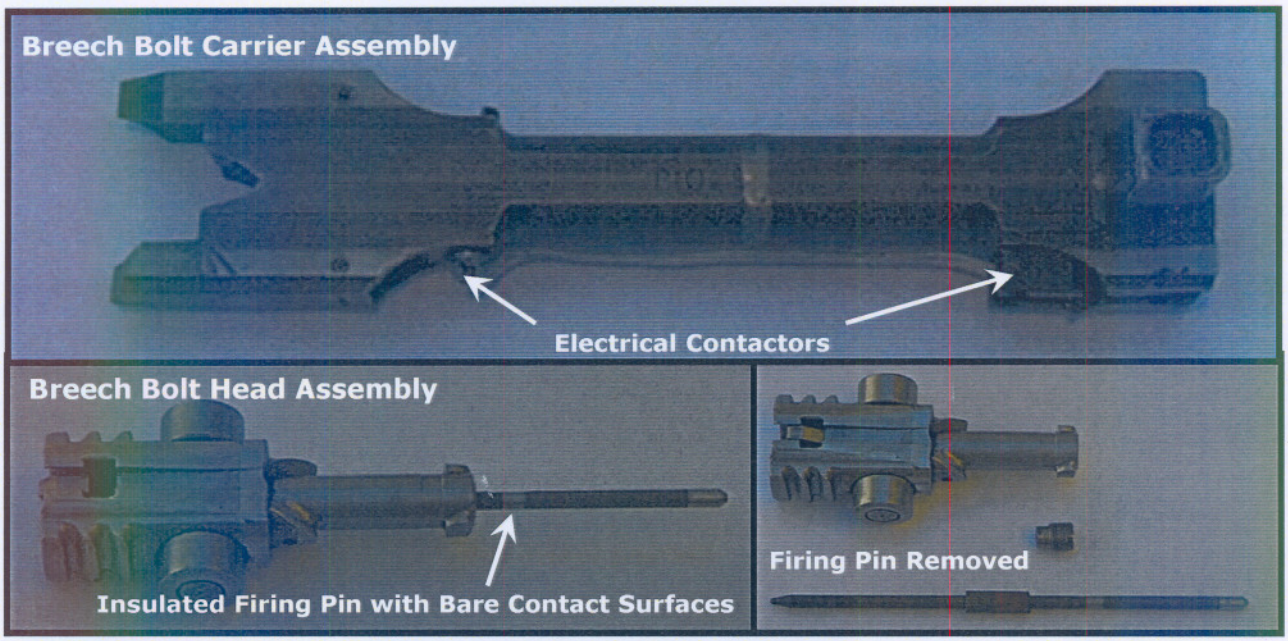


Figure 36: Breech Bolt Mechanism Group with Electrical Firing Pin

Standard type GA1 MG151 links were used to convey ammunition from the magazines through the flexible chute to the weapon for all the types of ammunition with the exception of the 20x102 mm rounds. Accommodating the 20x102 mm rounds, a new prototype link was developed. [060] Prototype links were made available for testing and demonstrating GAMA.

GA1 20x82 mm and 12.7x99 mm barrels could be used with the GAMA as standard items without alteration. Barrels launching 20x102 mm, 20x110 mm and 14.5x114 mm had to be designed to interface with the GAMA. The facility for rapid removal and replacement of barrels during calibre changes was one of the features of the new barrel design.

Both the 20x102 mm long and short barrels together with the 20x110 mm barrel were equipped with standard muzzle brakes. The geometrical appearance of the GAMA, when configured for the firing of the various types of ammunition, is only noticeable in the appearance of the barrel.

The natural frequencies of these barrels were determined to ensure that they do not coincide with the weapon's structural and firing rate frequencies.

This would have compromised the weapon's accuracy. Throughout the development of GAMA, aspects relating to the mass and natural frequencies were constantly noted.

The performance requirements of springs for the GAMA to perform within specification were established by simulation. Due to Röhrs' speciality in manufacturing multi stranded springs, they were contracted to design and manufacture the recoil springs for GAMA (Annexure M2). Written communiqués between the author, Cape Manufacturing Engineering (CME) and Röhrs regarding the recoil spring's performances were also registered. [061]

The product baseline for the GAMA, enables the firing of percussion type ammunition (12.7x99 mm; 20x82 mm; 14.4x114 mm; 20x110 mm) and electrical primed ammunition (20x102 mm). [062] [063]

5.3 Manufacturing

The development of GAMA required both significant creative engineering development skills, as well as an equally important contribution from the operations department. Latest technology equipment, such as 4 axes CNC machines, electrical discharge machines to perform spark - and wire eroding processes, were used in the manufacturing of components according to an approved GAMA concept base line. [064]

The challenge, however, was not only to manufacture a new GAMA, but also to prove that the old GA1 weapons hardware can be upgraded towards a GAMA status.

In this case, skills, tools and control processes required for the manufacturing of components were not enough. Metallurgical expertise was now also required to certify welding processes that were to be used to

produce GAMA partially from existing GA1 weapons, (as if it was machined out of solids). No welding or subsidiary flaws could be tolerated. Non Destructive Testing (NDT) inspections were performed on all hardware before being released for service.

Depending on the ammunition firing configuration, the composition of the GAMA experimental hardware comprised a combination of any of the following:-

- New unique developed hardware
- Standard GA1 hardware.
- Sacrificing old GA1 hardware to produce new GAMA hardware.
- Standardized hardware.

For this project, manufacturing was based on the production of low volumes of hardware. However, for the life cycle of the product, full scale commercial mass production of the GAMA still needs to be preceded by an industrialisation process. These processes are still to be evaluated.

5.4 Testing

The development of GAMA in a mechanical and electrical configuration together with the development of a 20x102 mm link, required that all possible technical catastrophic failures, critical issues, operational failures and interfaces were well documented. This information is given in the Test and Evaluation Master Plans. [065] [066] [067]

Many tests and demonstrations were conducted during the development of GAMA in its various configurations. Prior to each event, a procedural specification was drawn up, covering all proceedings and safety related issues. [068] [069] Apart from the numerous specifications covering the development of GAMA, there were also additional items such as the

procedural test specifications covering the development and the integration of various mounting interfaces. These included i.e. the following:

- Mutually interdependent performance checks
- Various mounting integration checks
- Intelligent cradle development (Soft Recoil)
- Acceptance tests for the cradle development. This also included scheduled tests on GAMA when integrated with IST's new chin mount for the Light Utility Helicopter (Tests were conducted in exactly the same manner as described in Chapter 3.3.).
- Ad-hoc evaluation requests for verification purposes (Chapter 5.2).

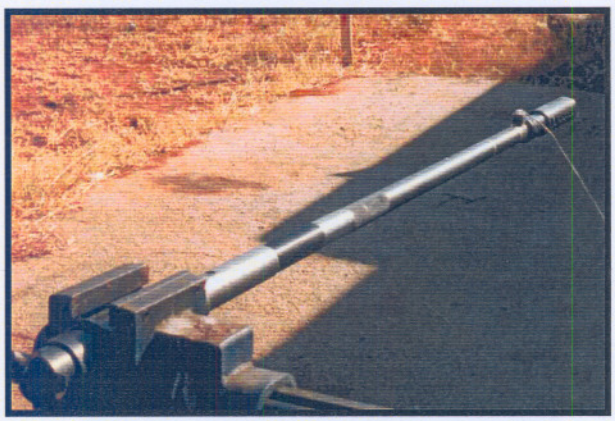


Figure 37: Frequency Spectrum Check on a 20x102 mm Barrel

Prior to each test or demonstration, the weapon was thoroughly examined to determine the condition of all components. The infrastructure during each test included a comprehensive coverage of the various disciplines that were required in the development of GAMA. Real Time Data Acquisition, NDT methods (e.g. Dye Penetrate as shown in Figure 38) together with Computer Aided Design, High Integrity Structural FEA and Dynamic simulation (Motion) packages, were used interactively during development tests. The advantage of this was that theoretically motivated changes could be predicted, immediately physically implemented and evaluated on site.

Although dye penetrate was used on the test site, a more intense NDT crack tests was performed using a Magnaflux testing unit, together with ferromagnetic particles (Tiede Fluoflux). Magnetizing was performed in a

longitudinal/circular/multidirectional technique. These later crack tests were performed on all major components and are compulsory for the issue of a Certificate of Conformance (COC), releasing the weapon for service.

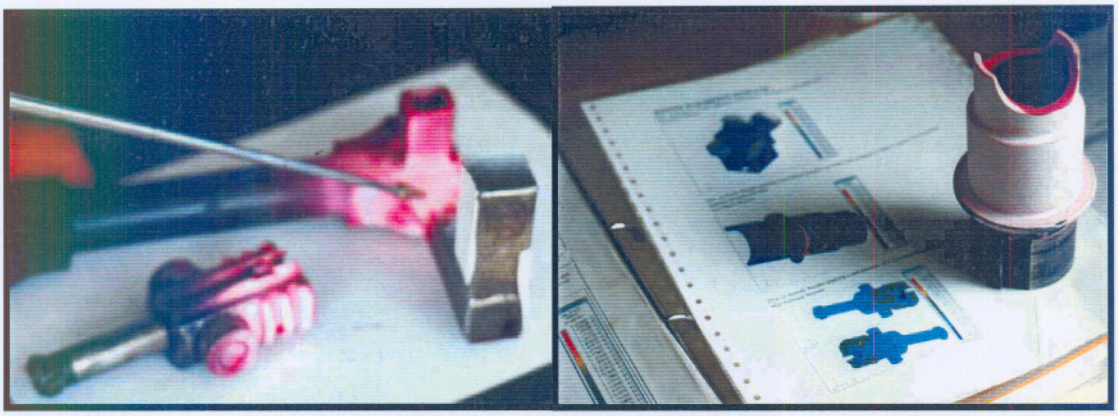


Figure 38: NDT and FEA Results Interactively Used

These tests were frequently performed throughout the development. They were conducted in accordance with ASTM E709-85, where the reference sample size was obtained from MIL-STD-105D Tables I & II.

The performance evaluations earned a significant level of trust from team members, clients and spectators. Nevertheless, GAMA was always fired remotely from behind cover to ensure the safety of all personnel and attendees. Permission was only granted to fire the weapon manually, once it had been certified as "Qualified".

5.5 Results

Table 2 shows an extract from the simulated and actual results of the GAMA firing 20x82 mm ammunition.

The GAMA was subjected to extensive field firing tests. Results were contained in many formal and informal reports that covered the achievements to date. The formal reports reflect the results that were

obtained during the system identification trials of the GA1 #1138, and the GAMA development and the unique GAMA cradle development for the GAMA. [070] [071]

Table 2: Extract - GAMA Simulation and Test Results

GAMA: 20x82 mm Ammunition			
DESCRIPTION	**TESTS**	**SIMULATION**	**DIFFERENCE**
Ignition @ 0.0 ms (Starting of Cycle)	-	-	-
Bolt at sear during recoil motion	37.5 ms	37.5	0%
Time to reach maximum breech travel	40 ms	42 ms	5%
Maximum recoil force	15.8 kN	15.3 kN	3.2%
Maximum barrel recoil	22.3 mm	24.6 mm	10.3 %

An extract of the results attained in the aforementioned reports are as shown in Table 3:-

Table 3A: Extract - GAMA Performance Measurements

RATE OF FIRE MEASUREMENTS		
WEAPON IDENTIFICATION	**CONFIGURATION**	**RESULTS [Rds/min]**
GAMA $_{\text{Mechanical}}$	12.7x99 mm Ammunition	590
GAMA $_{\text{Mechanical}}$	20x82 mm Ammunition	709
GAMA $_{\text{Mechanical}}$	14.5x114 mm Ammunition	776
GAMA $_{\text{Electrical}}$	20x102 mm Ammunition	819
GAMA $_{\text{Mechanical}}$	20x110 mm Ammunition	761

Table 3B: Extract - GAMA Performance Measurements

MUZZLE VELOCITY MEASUREMENTS		
WEAPON IDENTIFICATION	**CONFIGURATION**	**RESULTS [m/s]**
GAMA $_{\text{Mechanical}}$	12.7x99 mm Ammunition	827 - 832
GAMA $_{\text{Mechanical}}$	20x82 mm Ammunition	688 – 704
GAMA $_{\text{Mechanical}}$	14.5x114 mm Ammunition	1003 - 1028
GAMA $_{\text{Electrical}}$	20x102 mm Ammunition	1007 – 1036
GAMA $_{\text{Mechanical}}$	20x110 mm Ammunition	795 - 820

5.6 Conclusion

The practical field tests demonstrated that all the design requirements of the GAMA weapon were successfully met over the entire range of the intended calibres.

CHAPTER 6 HISTORICAL PROJECT OVERVIEW AND CONCLUSIONS

6.1 Overview

The development of GAMA was for the author a project full of unknowns, challenges and successes. As an analyst on numerous projects, his proven expertise in field and laboratory testing, his successes in simulation, and the comprehensive knowledge of the GA1 and other rapid fire weaponry, granted him the opportunity to scientifically chair the development of GAMA in his capacity as Design and Systems Engineer.

A brief summary of the highlights is given here so that the reader can appreciate the complexities of this project and the uniqueness of its contribution.

During March 1996, the possibility of modifying the GA1 weapon to fire 20x110 mm ammunition was first voiced. On 23 August 1996, after the formal approval by Vektor Management for the development of a GAMA, the study of the GA1 weapon system's behavioural pattern started. An accurate test database was opened to capture all events from the GA1 system identification phase, progressively throughout the development of the GAMA. The test data-base was named Gam_dbt1.xlw. It contained a history log of test events as well as the following:-

- Weapon Configuration
- Platform/Mount
- Test Date and Time
- Test Number
- Control State of the Weapon
- Ammunition & Link Data (Type, Identification, Consumption (Loaded, Fired, Duds))

- Instrumentation Equipment – Serialized (Type, Position, Description, Calibration, Auxiliary Equipment)
- Stoppages
- Remarks

Table 4 is an extract from this Test Data Base and highlights certain major events such as the first firing in South Africa of 20x102 mm rounds and the subsequent successful firing of 14.5x114 mm rounds.

Whereas the development of new weapons usually requires about 25 000 rounds, in this case (due to the world-wide weapons boycott) only about 1000 rounds of the 20x102 mm were available. These were purchased via third parties amidst great secrecy. Of these, only about 600 rounds were actually fired in the development of the GAMA. This fact further demonstrated the power of simulation, and the new techniques developed by the author in this project.

By October 1996 simulation models of the GA1 were completed and verified against test data. GAMA simulation models, and the firing of 20x102 mm ammunition as part of the range, followed.

The unavailability of 20x102 mm, 14.5x114 mm 12,7x108 ammunition and the replenishment of 20x110 mm ammunition was a reality. Development through simulation proceeded using the theoretical data available at the time. The progressive evolvement of GAMA simulation models created a data base defined as GA1&GAMA1_Data.xls. This incorporated the simulation configuration details of both the GA1 and the GAMA simulation models. Both these electronic data base files were updated continuously throughout the GAMA project and are kept on the company server for traceability and future references.

Table 4: Extract - Test Database Gam_dbt1.xlw

DATE	TEST No.	WEAPON	CONFIGURATION	REMARKS
23 Aug 1996 – 2 Oct 1997	R001t1[4] - R002t16	GA1 #1138	20x82 mm Pracs	System Identification Dry Cycling and Firing
2 Oct 1996	R003t1 - R003t03	GA1 #1138	12.7x99 mm Ball	System Identification Dry Cycling and Firing
22 Oct 1996			12.7x99 mm Ball	
21 Jan 1997	R004t1 – R004t99	GA1 #1138 & Ammunition	20x82 mm and 12.7x99 mm	Laboratory Tests: Weapon Mechanisms & Stripping Forces
10 March 1997 - 13 March 1997	R005t1 – R006t3	GAMA1M[5]	20x110 mm 20x82 mm	System identification tests. Weapon & Cradle interface evaluation. Dampers (cradle) adjustments/changes
13 March 1997 - 18 March 1997	R007t1 - R008t5	GA1	20x82 mm	System identification tests. Verify weapon behaviour when firing copper and steel cartridge cases
18 March 1997	R009t1 - R012t1	GAMA1M	20x82 mm 20x110 mm 12.7x99 mm	System identification tests.
18 March 1997	**R011t1**	**GAMA1E[6]**	**20x102mm**	**Static Test 20x102 mm Ammunition Arrival** Verify first round's ignition voltage Electrically 160V DC (Figure 40)
19 March 1997	R012t2 - R012t3	GAMA1M	20x82 mm 20x110 mm 12.7x99 mm	System identification tests
19 March 1997	**R013t1**	**GAMA1E**	**20x102 mm**	**Fire 20x102 mm round for the first time ever in the RSA**
12 November 1997	**R047t1**	**GAMA2M**	**14.5x114 mm**	**GAMA fire 14.5x114 mm round for the first time**

Imported ammunition only arrived during the course of the tests at Pietersburg (Figure 39). The detonation voltage was verified (Figure 40) and shortly afterwards the GAMA fired 20x102 mm with resounding success (Figure 41).

[4] R001 is the Test Configuration and t1 the Test Number
[5] GAMA in a Mechanical Configuration
[6] GAMA in a Electrical Configuration



Figure 39: Ammunition Arrived on Tuesday 18 March 1997

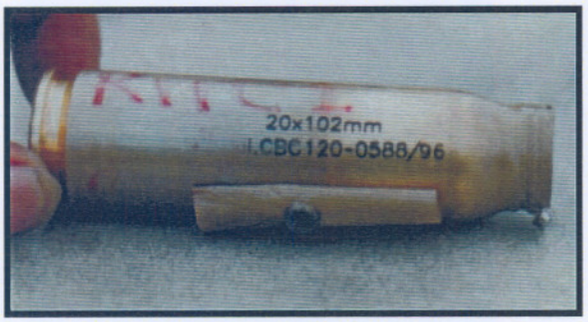


Figure 40: Cartridge Case after Static Test # R011t1



Figure 41: Author, Colleagues and Friends Celebrate 19 March 1997

The resultant publicity generated by the successful firing of the 20x102 mm was gratifying. Despite the firing of 12.7x99 mm, 20x82 mm, 20x110 mm

and 20x102 mm (electrical primed ammunition), the drive was now on to fire the remaining 14.5x114 mm ammunition with success.

The Project GAMA drew a significant amount of attention throughout its development. The uniqueness of the weapon and what it offered was soon acknowledged by all. The rapid progression of the project due to the intensive use of simulation and testing (which was novel at the time) resulted in worldwide interest in GAMA.

Clients explored the possibility of obtaining and integrating the GAMA as part of their own inventory, covering Air-, Naval- and Land armament platforms. The successes also stimulated spontaneous participation and involvement by 3rd party ammunition and platform manufacturers. Joint ventures would definitely have resulted in an expansion into various markets, but was not considered by Vektor as a market strategy at that time.

The following extracts are highlights from the author's diary, illustrating the pace at which this project advanced:-

- **August 1996:** GAMA development initiated by exploring GA1 behaviour and generating comparative simulation models.

- **October 1996:** Accredited simulation models of the GA1 were completed. The generation of simulation models on the GAMA started. Results were used to manufacture a GAMA capable of firing electrically primed 20x102 mm ammunition.

- **March 1997:** First firing of 20x102 mm ammunition.
  Data captured during the firing of 12x99 mm, 20x82 mm, 20x110 mm and now 20x102 mm is extensively used as verification for the GAMA simulation models.

- **May 1997:** GAMA Presentation at Vektor for ARMSCOR and the SAAF Light Utility Helicopter turret project team.

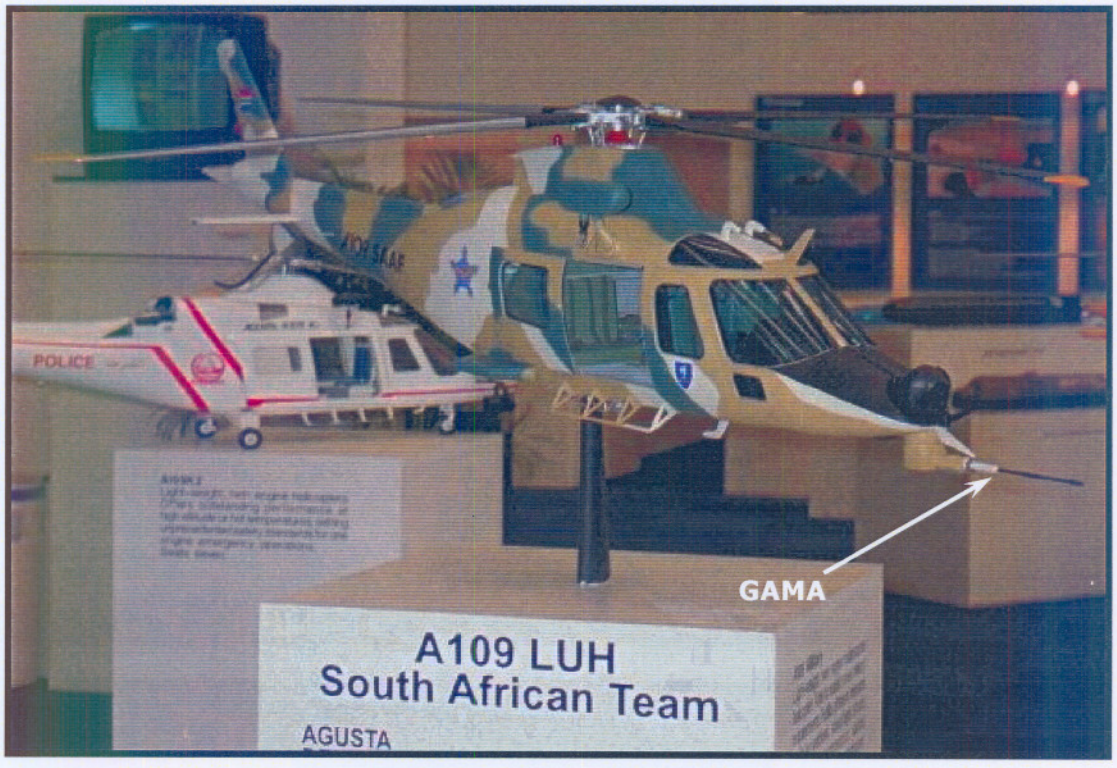


Figure 42: Photo showing the new Augusta A109 LU Helicopter

Figure 42 is a photo that was taken during the Defence Exhibition South Africa (DEXSA'98) show at Air-Force Base Waterkloof where the chosen LUH for the SAAF was announced and shown for the first time. A mock-up of the chin mounted turret with the GAMA was also shown.

- **July 1997:** Firing Demonstration at Harley Valley, South Wales for the United Kingdom Armed Forces.



Figure 43: Photo of the Test South Wales Test Site

During this live firing demonstration, Vektor's machine guns, 40 mm Automatic Grenade Launcher (AGL), Gun Infantry Two (GI2) , Gun Aircraft One (GA1) and the GAMA in action firing 20x102mm ammunition were successfully demonstrated (Annexure K1).

- **July 1997:** Firing Demonstration at SAAF Roodewal Bombing Range Pietersburg for the Brazilians (Annexure K2).

  Members of SAAF also participated in the demonstration by explaining the history behind the GA1 and the role it played on the present Allouette Helicopter Gun Ships, which are to be phased out in the near future. The replacement will be the new Light Utility Helicopters which are to be equipped with a GAMA. The role of the GAMA when fitted on the LUH was also briefly explained.

- **July 1997 & August 1997:** Two separate contracts were placed by SAAF URS (Project Officer Lt P.D Wroegemann) & ARMSCOR LMH/S/302/6/P02797 (Program Manager G.F.S. Hattingh) [004]
  These were:
  - Vektor for the development of GAMA
  - IST for the development of a chin mounted turret similar to what has been fitted to the Rooivalk Attack Helicopter.

- **November 1997:** GAMA fired first 14.5x114 mm ammunition.

- **June 1998:** The SANDF provided ammunition for development.
  The requirement for 12.7x108 mm and 14.5x114 mm ammunition was solved when the SANDF provided ample ammunition as a CFE to assist in proceeding with the GAMA devolvement.

- **July 1998:** Demonstration. GAMA firing 14.5x114 mm ammunition.

- **September 1998:** Infantry Symposium-Infantry School Oudtshoorn



Figure 44: Infantry Symposium Exhibit Area Presenting the GAMA

The GAMA, together with other armament, was exhibited and successfully demonstrated.

- **October 1998:** Firing Demonstration at Paardefontein
  The GAMA together with the 40 mm AGL was demonstrating their firing power to ARMSCOR and the SAAF's LUH project team.

- **November 1998:** Drafting an International Press Release for the GAMA and its versatility (Annexure K3).

- **November 1998:** DEXSA'98 International Armament show at Air Force Base Waterkloof and Firing trial at Paardefontein (Annexure D)



Figure 45: GAMA, Vektor's Prime Attraction

The GAMA and its versatility draw a lot of international attention. Its simplicity in logistical support made a positive contribution.

- **November 1998 – May 1999:** Negotiations with International ammunition manufacturers to become sole suppliers of ammunition for the GAMA (Annexure K4).

- **December 1998:** Milestone – GAMA Firing Test Report and Simulation report on the newly developed intelligent soft mount.

- **March 1999:** GAMA Integration with IST turret. Live firing tests at Roodewal Bombing Range Pietersburg.



Figure 46: GAMA Fired when Integrated with the Chin Mount

- **April 1999:** GAMA Integrated into IST's Chin Mount Turret and Kentron's Helmet Sight. Live firing trials at Paardefontein, Pretoria.



Figure 47: GAMA Fired from the Remote Controlled Chin Mount

- **June 1999:** Presentation at Vektor for the SANDF Land Forces.

- **June 1999:** Program Manager Guided Missiles Systems ARMSCOR arrange for more ammunition to be made available for GAMA

SANDF provided the ammunition from De Aar, Naboomspruit and Jan Kempdorp.

Figure 48 illustrate the trip undertaken where the author and his team personally transported 12.7x108 mm, 20x82 mm, 14.5x114 mm and 20x110 mm ammunition from the military bases De Aar, Jan Kempdorp and Naboomspruit to PMP.



Figure 48: SAMIL 100 Transported Ammunition

- **July 1999:** Integration of GAMA with AMS (Aerospace Monitoring System) Overhead Weapon System (OWS) platform performing live firing demonstration to the SANDF (Annexure K5).

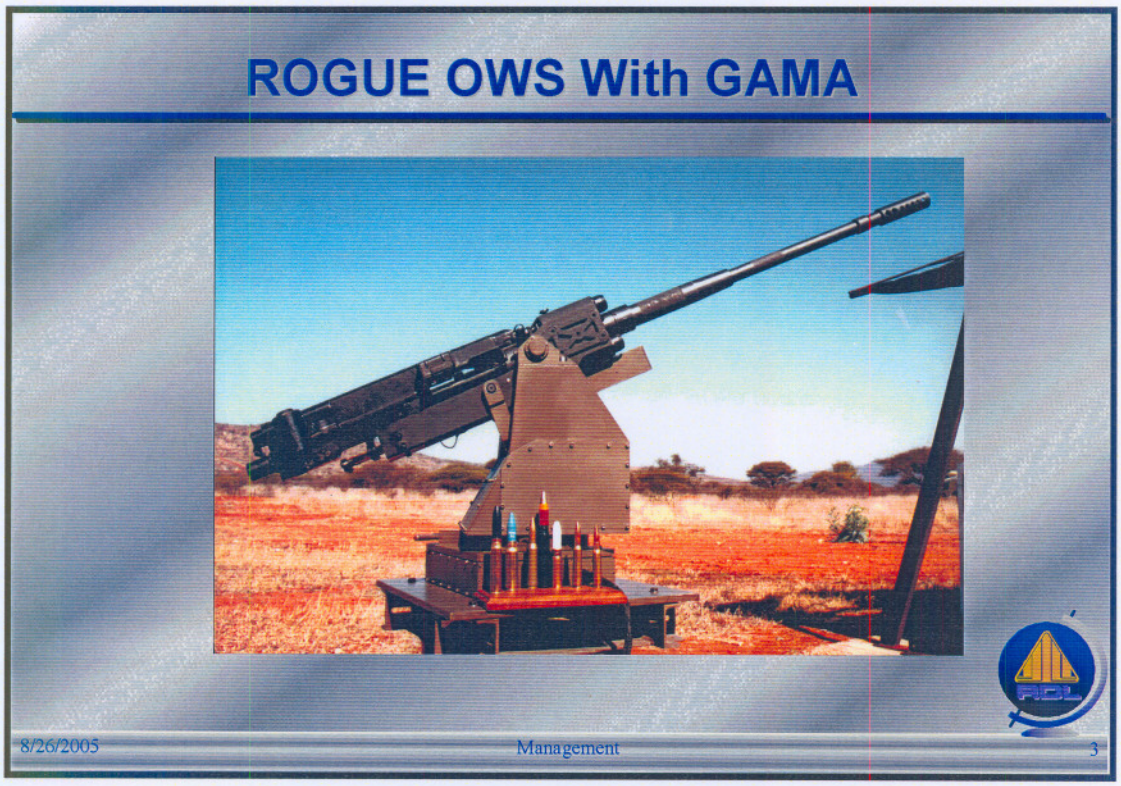


Figure 49: GAMA Mounted on Servo-Controlled and Observation System

During this demonstration superb accuracy was encountered when firing the weapon at a prescribed 4.7 Hz firing frequency. This frequency was prescribed to ensure that it was outside the structural-, weapon control frequencies.

- **August 1999:** Demonstration to Tanzania firing the GAMA from the OWS platform (Annexure K6).

- **February 2000:** Presenting GAMA at EUROSATORY International Armament Show (Annexure K7).

- **May 2000:** Request for Quotation GAMA with conversions 12.7x99 mm and 20x102 mm Ammunition for the Black Hawk UH-60 (Annexure K8).

- **February 2002:** Directorate Air Force Division requesting the status of the GAMA to be fitted on the Augusta A109 Helicopter (Annexure K9).

- **May 2004:** Embraer requested the status of the GAMA in a Gun Pod for exported aircraft (Annexure K10).

- **April 2005:** The editor of book "Rapid Fire" suggested the expansion of GAMA towards the utilization of 23x115 mm ammunition (Chapter 6.4 & Annexure D11).

6.2 Overall Results

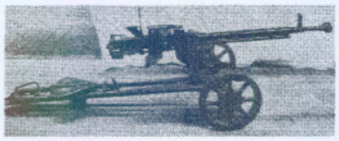
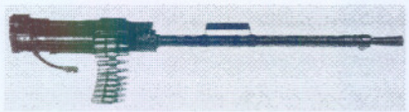
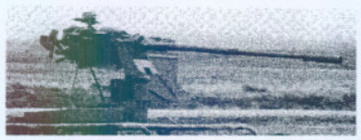
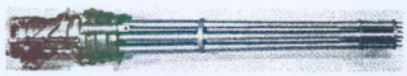
Results obtained were of a high standard and were constantly being requested by 3rd parties so that they could proceed with development in their own field of expertise (Annexure B).

Within its various configurations the GAMA was always compared favourably with other competitive weaponry.

Calibre conversions on GAMA can be performed in the field within 10 minutes without the use of special tools and skills. (See Table 5) All data and photos were extracted from Jane's Infantry Weapons. [072]

Table 5: Weaponry Reference Table

WEAPON IDENTIFICATION	AMMUNITION TYPE	MASS [kg]	MUZZLE VELOCITY [m/s]	FIRING RATE [rds/min]
 Manroy 0.50 M2CB Machine Gun on a M3 tripod	12.7x99 mm (0.50 Browning)	38.5	893	450 - 500

WEAPON IDENTIFICATION	AMMUNITION TYPE	MASS [kg]	MUZZLE VELOCITY [m/s]	FIRING RATE [rds/min]
 12.7 mm DShK-38 Heavy Machine Gun on a Sokolov Mount	12.7x108 mm	35.7	860	575 - 600
 GA1	20x82 mm	39	720	650 - 750
 14.5 mm KPVT Heavy Machine Gun for Armoured Vehicles	14.5x114 mm	49.1	1000	600
 Giat Industries 20 mm M621 Cannon mounted on a Land Rover	20x102 mm	49	990 – 1025	800
 Lockheed Martin 20 mm M168 Six-barrelled Cannon is the M61A1 Vulcan Aircraft Gun	20x102 mm	136	1036	1000 - 3000
 GAMA	12.7x99 mm 20x82 mm 14.5x114 mm 20x102 mm 20x110 mm	47 48 50 50 53	820 720 1030 1030 850	500 – 600 600 – 700 750 – 850 700 – 800 600 - 700

In addition to Chapter 6.1, the GAMA was demonstrated and fired successfully from various local and 3rd party platforms including a M3 Tripod (Figure 50).



Figure 50: GAMA 20x102 mm Mounted on a M3 Tripod

Although the GAMA was not fired from the standard GA1 Helicopter door mount (Figure 51), it was fired remotely from the replacement cradle.

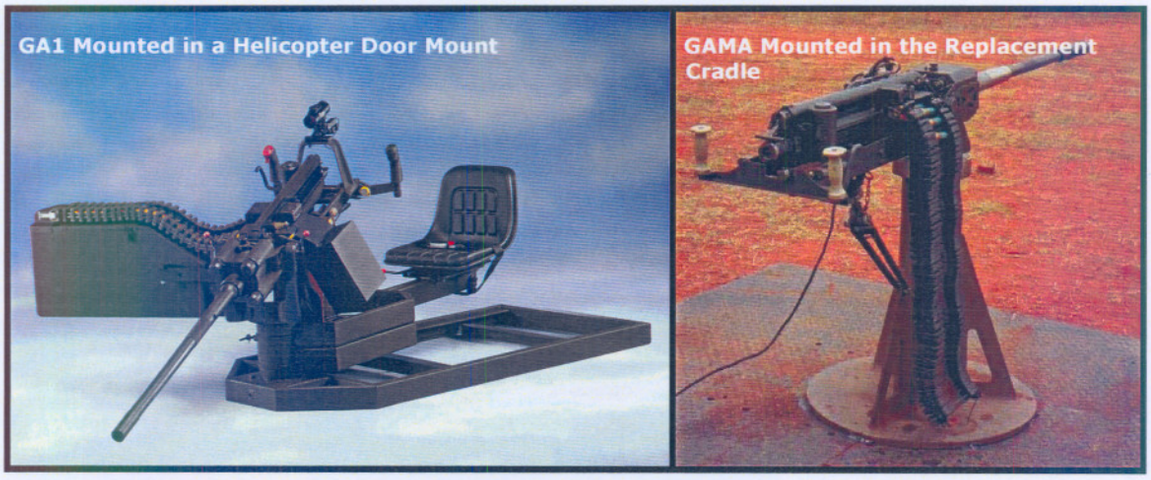


Figure 51: Helicopter Door Mount and Laser Cradle

The next phase would have been to integrate the GAMA into the Fixed Wing Gunpod that was developed, manufactured and tested by Vektor (Figure 52). This Gunpod was already being subjected to stringent qualification and flight clearance tests. [073]

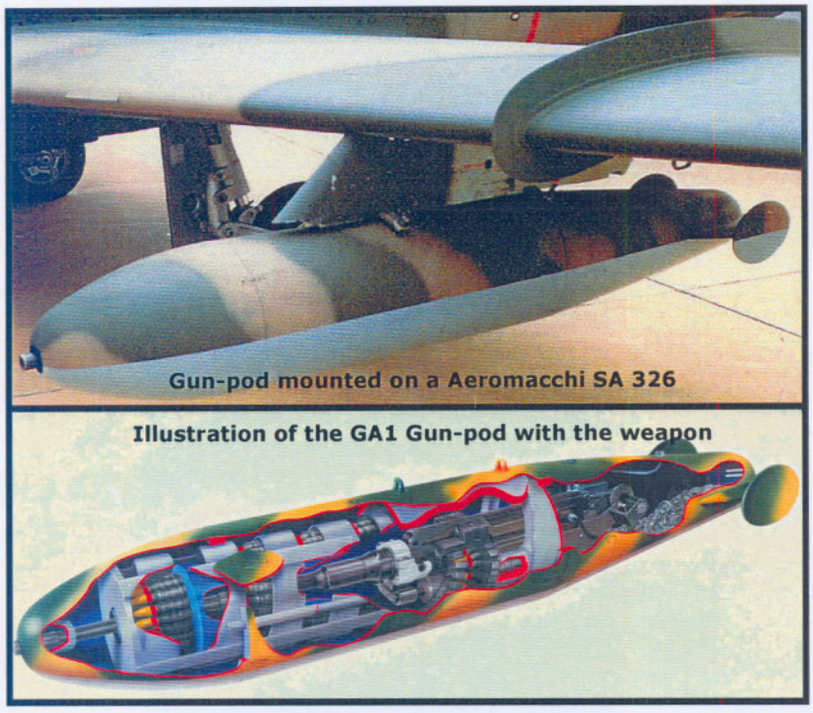


Figure 52: Illustration of the GA1 Gunpod

6.3 Conclusions

This study has shown that the development of a rapid firing, multi-calibre gun with the aid of simulation is possible. Simulation also ensures that future growth capabilities are catered for.

This thesis also successfully demonstrated that simulation and testing methodologies can be used interactively in order to minimise the building of experimental hardware, and in so doing reduce time scales and costs.

This philosophy introduces a mind shift in development engineers towards the definite use of simulation in any project that is tightly bound to cost and time constraints. Simulation opens the way for the generation and conceptualising of new ideas, and allows more options to be tested rapidly with great success.

During the life of this project, a trend towards an acceptance of the value of simulation, and its increasing use, was evident. The foundation has now been laid for the extensive and appropriate use of simulation.

6.4 Recommendations

As stated in Chapter 5.3 the GAMA still needs to be subjected to full scale qualification and industrialisation phase before commercial deployment can result. In view of the intense market interest, it is recommended that this is initiated speedily.

In the first quarter of 2005, Vektor migrated with LIW to form a new company called DLS Lyttelton. This merger thus provides favourable conditions to proceed with GAMA to address the requests frequently received. (Annexures K8; K9; K10). [074] [075] [076]

Further expansion of the weapon, with regard to the firing of a diversity of ammunition, (including 23x115 mm calibre) should be considered (Annexure D11). [077]

Development of the intelligent soft mount for the GAMA and its subsidiaries should also proceed.

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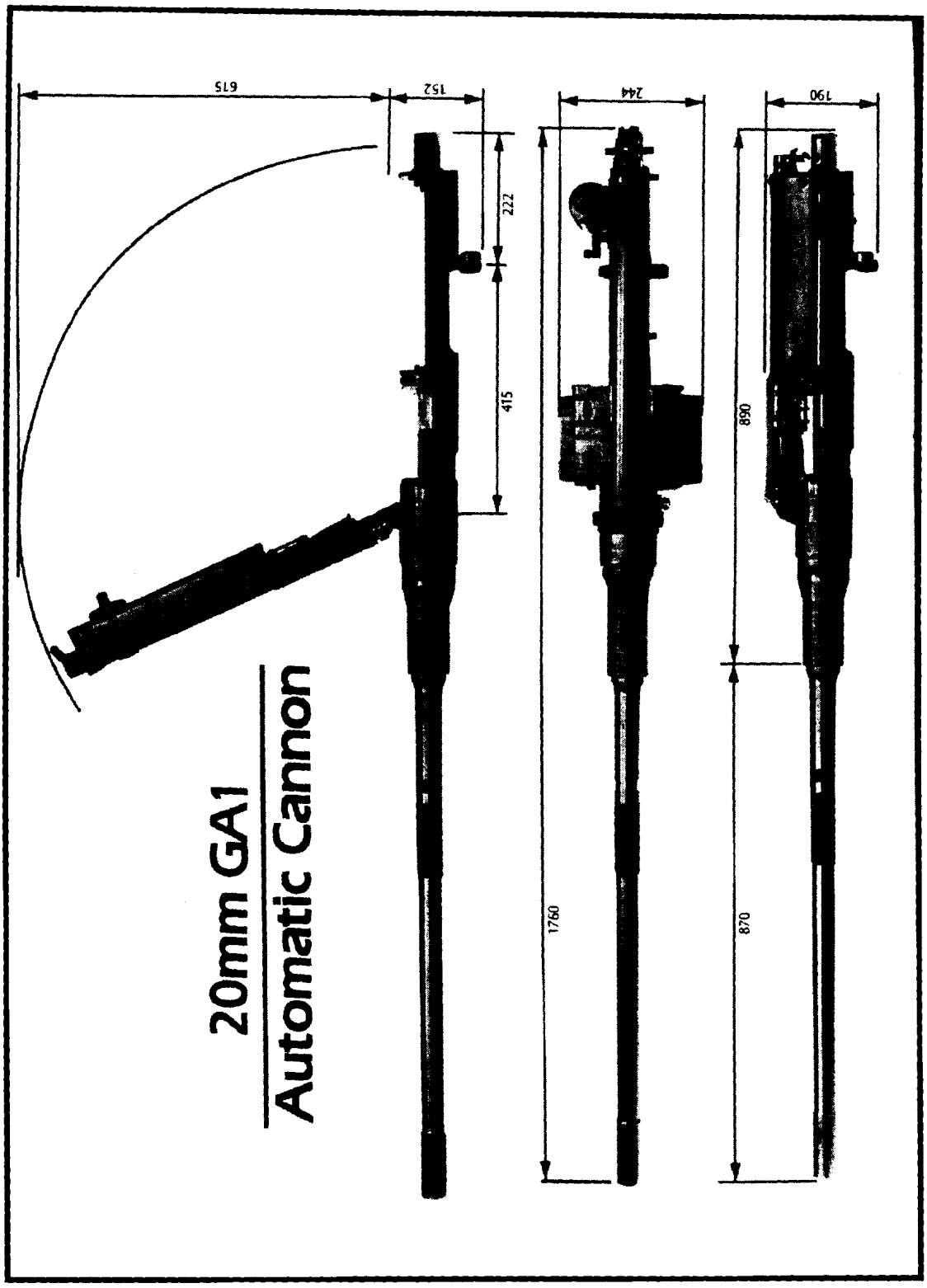
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A. GA1 WEAPON SYSTEM



B. CSIR GRATITUDE LETTER - PhD TEST DATA

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N Davids
CSIR DEFENCETEK: ATPP

C. REPORT FROM AN INDEPENDENT RESEARCHER - CSIR

REPORT of literature review for Andre van Heerden

TOPIC: The development of an automatic multi-calibre weapon system by means of simulation and testing

Searches were done by Erna Meyer (Information Specialist for Crime Prevention at the CSIR) on a variety of databases and search engines. Because of the very specific topic it was necessary to use several keywords in different combinations. With the background information received from Andre van Heerden it was possible to find suitable keywords to cover the research field. Variations in spelling of certain keywords were necessary to find relevant information. It was important to use search engines that cover a broad spectrum, but to employ advanced search methods in order to narrow certain aspects and get the most relevant information. It was important to cover international academic as well as inter-disciplinary South African databases. Because of the topic it was useful to cover military as well as patent databases. And because it is for Phd purposes it was important to search dissertation databases – international as well as local - to see if it is an unique topic and not already registered as a Phd/thesis.

Background Information:

Conversations between information specialist and Andre van Heerden

Press Releases (Denell)

International Shows (Idex)

Articles in newspapers:

**Beeld (Nov 98)
**Pretoria News
**Armada International (99)
**Soldiers of fortune (Feb 99)
**Press Middle East (Nov 98)

Photos

KEYWORDS:

Multiple/multi calibre/caliber
Multiple/multi calibre/caliber weapon systems
Medium calibre/caliber weapon systems
Duel calibre/caliber
Calibre/caliber conversion
Weapon systems
Development of multiple/multi calibre/caliber weapon systems
Multiple/multi calibre/caliber firing systems
GAMA
Gun Automatic Multiple Ammunition
Simulation

Zebra
(no results)

Aardvark
(no results)

Ananzi
(no results)

CONCLUSION

Found results on some of the databases, but only information that is already worked into the Phd (see file for commentary).

Found articles in Daily News and Jane's Defence (van Heerden's own development)

Apart from results from databases and search engines covered, and the commentary of Andre van Heerden on the results, nothing new was found.

For more detail on results see file.



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D. PUBLICATIONS RELATED TO THE GAMA PROJECT

The GAMA development was published locally and internationally. Coverage was thoroughly covered in the media.

1) Media Release DENEL (Pty) Ltd 17 November 1998

Subject "GAMA" Fires Five Different Calibres.
Author Sam J Basch

D E N E L

DENEL (Pty) Ltd
Reg No. 92/01337/07

Facsimile

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FROM SAM J BASCH ISSUE DATE NOVEMBER 1998
EMBARGO **17 NOVEMBER 1998**

MEDIA RELEASE

SUBJECT "GAMA" FIRES FIVE DIFFERENT CALIBRES

A novel multi-calibre weapon system, designated "GAMA" (Gun Automatic Multiple Ammunition), is shown for the first time at the DEXSA 98 exhibition, taking place at Waterkloof, South Africa, from 17 to 21 November 1998.

Developed by the South African Denel Group's Vektor division, the GAMA achieved what was deemed difficult, if not impossible, to do accommodating different calibres within a single weapon system.

It is currently chambered to fire five (5) different calibres, i.e. 12.7 x 99; 20 x 82; 14.5 x 114; 20 x 102; and 20 x 110 HS 404/804. Considerable progress has been made to also fire 12.7 x 108 ammunition. These are the most common medium calibres currently in service worldwide.

Added versatility was designed into the system by allowing feed from either left or right hand

The GAMA weapon system consists of a single baseline weapon with various conversion kits. Due to its simplicity of design and ease of interchangeability, converting from one calibre to the next is accomplished without any tools. No adjustment for headspace is required. The conversion time varies between one and ten minutes only.

Given its numerous applications, combined with the advantages of a single weapon configured to fire different calibres, GAMA provides unparallelled cost savings in operations and logistics.
.../more gama

The GAMA is the only weapon currently available that accommodates both percussion primed or electrically primed ammunition in a single weapon. It can be either manually or remotely activated and controlled.

The main advantages of GAMA are

- A single weapon can be configured to fire six different calibres, a feature which allows for a calibre dedicated to a specific task;
- With a single weapon in inventory, upgrades to a different configuration are accomplished by means of a simple calibre conversion kit;
- No tools or special skills are required to execute conversions;
- It is not necessary to change headspace when converting;
- Low maintenance and training cost;
- Simplified logistics;
- Controllable firing rate for all calibres to a maximum of 850 rpm (14.5 x 114), electrically primed ammunition can be fired from the closed breech if required;
- Remote firing and control only requires 28V DC for any of the given calibres (percussion primed or electrically primed ammo).

The GAMA was designed to interface with all existing Vektor GA-1 platforms, which is an advantage for domestic and export clients who have this Vektor product in inventory.

The versatility of the GAMA system is evident in its wide range of applications, including

- **Ground to Ground**

M3 tripod-mounted, Light Utility Vehicles, Special Operations Vehicles, eg. LAV's, turret-mounted in MICV's, troop carriers and reconnaissance vehicles.

- **Air to Ground / Air to Air (rotary wing aircraft)**

Pod, Door and Chin / Belly-mounted.

- **Air to Ground / Air to Air (fixed wing aircraft)**

Wing and Pod-mounted, eg. subsonic and prop-driven trainers and COIN aircraft.

- **Naval (typically pintle and pedestal-mounted)**

Special Operations insertion craft, eg. inflatables; Strike Craft; and Coastal Patrol Craft.

In the development of the GAMA, the latest technologies were employed, including Computer Aided Design, Structural Analysis (Finite Element Analysis) and Dynamic Motion Analysis. All these processes were confirmed and proved to be successful using sophisticated data acquisition and data manipulation techniques.

Qualification of the weapon in 20 x 110; 14.5 x 114; 20 x 82; and 12.7 x 99 is scheduled for the first half of 1999.

NOTE For further details and technical information, visit the Denel stand A4 in Hall 8 at DEXSA 98.

End

LAV – Light Attack Vehicles
MICV – Mechanized Infantry Combat Vehicles
COIN – Counter Insurgency

2) **Pretoria News Friday 20 November 1998**

Subject on Page 1 SA develops a gun which fires different calibres.

Author Kim Helfrich (Defence Correspondent)

PRETORIA NEWS
FRIDAY NOVEMBER 20 1998

NEWS

SA develops a gun which fires different calibres

Kim Helfrich
DEFENCE CORRESPONDENT

What has previously been deemed difficult if not impossible – firing different calibres from a single weapons system – has been achieved by a Denel Group company.

The GAMA – Gun Automatic Multiple Ammunition – weapons system is currently chambered to fire five calibres – 12,7 x 99, 20 x 82, 14,5 x 114,20 x 102 and 20 x 110HS 404/804 – with "considerable progress" being made in firing 12,7 x 108 ammunition.

"These are the most common medium calibres currently in service worldwide," said a Vektor division spokesman.

The GAMA weapon system consists of a single baseline weapon with various conversion kits.

Simplicity of design and interchangeability make converting from one calibre to another possible without tools. Conversion times vary from one to 10 minutes.

"GAMA is the only weapon available which accommodates both percussion primed or electrically primed ammunition in a single weapon. It can be either manually or remotely activated and controlled," he said.

Applications include ground-to-ground, air-to-ground, air-to-air on fixed wing and rotary winged aircraft and naval, either pintle or pedestal mounted.

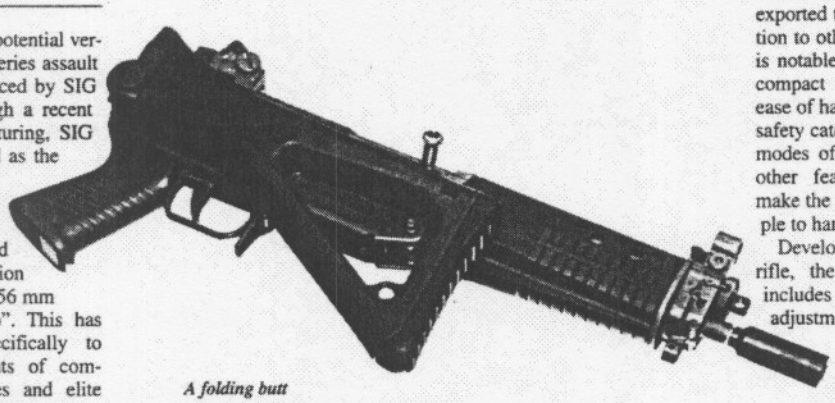
The South African-developed GAMA which can accommodate five different calibres from a single weapons system.

New commando assault rifle

BY BRIAN WALTERS

A new compact high potential version of the SIG 550 series assault rifle has been introduced by SIG Arms. Formed through a recent organisational restructuring, SIG Arms formerly traded as the Small Arms Business Unit of the SIG Group and displayed on the company's stand in the Swiss Pavilion (Hall 9), is the new 5.56 mm SG 552 "Commando". This has been developed specifically to meet the requirements of commando, special forces and elite units that may be confronted with sudden engagements at short to medium range.

The weapon is the latest in a series which began with the SG 550 standard model and was followed by the SG 551 SWAT series, some of which have been exported to Gulf countries in addition to other armies. The new rifle is notable for its light weight and compact dimensions, as well as ease of handling. An ambidextrous safety catch, folding butt and three modes of firing, are some of the other features that combine to make the SG 522 Commando simple to handle.



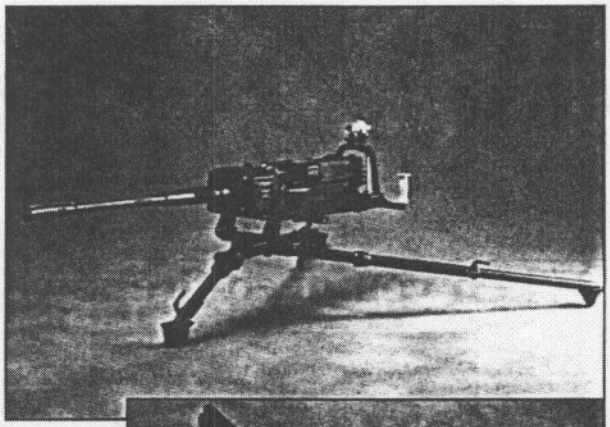
A folding butt eases use of the new SG 552 Commando assault rifle in short range engagements.

Developed specifically for this rifle, the Hensoldt 6x42 scope includes the facility for rapid adjustment for windage and elevation, while the reticule includes beta-light illumination. As an alternative, a Trijicon ACOG 3.5x35 combat scope can be fitted to the SG 552 to provide rapid target acquisition in day and night conditions by means of projecting an aiming dot into the reticule.

Vektor fields unique weapon

A multi-calibre weapon system that can fire ammunition of Western, former Soviet and Chinese origin, has been developed by the Vektor division of Denel, *writes Brian Walters*. Funded by the South African National Defence Force, the Gama (gun automatic multiple ammunition) weapon system promises to make for substantial savings for forces that hold ammunition stocks from a variety of sources.

Vektor claims that the Gama is the only weapon that accommodates percussion primed or electrically primed ammunition in a single unit. It is chambered to fire five different calibres, ranging from 12.7 x 99, to 20 x 110 HS 404/804, and the company reports that it is making progress in adding the former Soviet 12.7 x 108 ammunition. Together with 20 x 82, 14.5 x 114 and 20 x 102, these are the most common medium calibres in service worldwide.



The Gama weapon system (above) consists of a single baseline weapon with various conversion kits.

The simplicity of design and ease of interchangeability facilitates conversion from one calibre to the next without any tools. Conversion time varies between one and ten minutes and no adjustment for headspace is required

Dutch treat

Van Halteren Metaal BV, one of the world's leading manufacturers of artillery gun training simulators, is again exhibiting at IDEX. Key new developments on show are the Appended System, capable of being fitted to the operational equipment in less than eight hours, the ARES monitoring system for both training and operational ammunition, which displays and records all details of fuse, shell and charge loaded, and its road wheels for tracked vehicles. Van Halteren can be found in the Netherlands Pavilion, Hall 5.

Africa Aerospace and Defence 20

Dexsa and Aerospace Afric will be combining their bi annual expo for the year 2000. They will also celebrate the South African Airforce 80th anniversary. The venu is Waterkloof Air Base, 9th September 2000. Con Armscor (27) (12) 428 or AMD (27) (12) 428 3080.

4) ARMADA International 1/99

Subject on Page 53 DEXSA '98 and the Big Six – The Vektor Gama is flexibility itself.

Author Eric H Biass

Waterkloof Air Base, as the nozzle of its two barrels were crowned by a pair of familiar coils. On close examination, the latter indeed proved to be from Oerlikon Contraves and intended to program Swiss Ahead munition.

The 35DPG has been under development since 1994 for South Africa's corvette programme, is based on the 1984-vintage GA35 gun and does not penetrate the deck. The mount has recently completed a series of tests during which 6000 rounds were fired. However the next significant milestone is expected to be achieved in March with the planned firing of Ahead rounds. So far the agreement between Lw and Oerlikon Contraves, which dates back from 1995, only covers "mutual technical support," to use the terms of the Lw official interviewed by the editor. Unlike the Swiss gun systems that also rely on radar fire control, the Lw mount will only count on M-Tek stabilised electro-optical trackers and a laser range finder to track and kill aggressors.

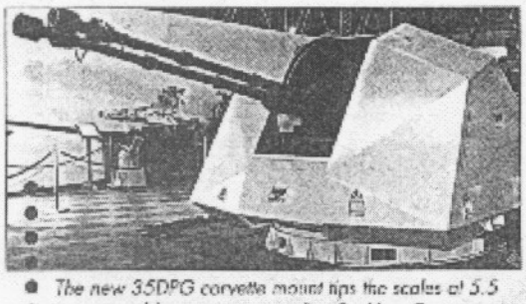
The Vektor Gama is yet another device that was unveiled at Dexsa. This gun not only manages the difficult feat of being able to fire five different calibres, but does so at a higher rate than the weapons these munitions were originally inteaded for. The Gama is particularly intended for those armed forces that are still equipped with older guns and that have large stocks of various munitions. Seen under this objective, the Gama indeed makes sense, as it would enable one to dramatically cut down training costs. The barrels (five are available) represent only about 15 to 20 per cent of the overall weapon cost. They are easy to change (no tools needed), and existing ammunition is simply re-packaged using very simple-to-use plastic links. The gun copes with both percussion and electrically primed ammunition, can be remotely controlled and mounted on light vehicles, helicopters and aeroplanes or ships. The Gama will be fully qualified at the beginning of 1999.

The South African Big Six

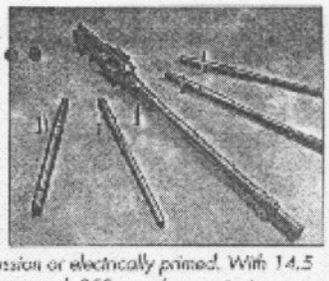
Corvettes: German Corvette Consortium, four units, valued at R 6 0001 million, estimated IP value R 16 007 million
Submarines: German Submarine Consortium, three units, valued at R5212 million, estimated IP value R 30 274 million
Naval helicopters: GKN Westland Navy Lynx, four units, valued at R 787 million, estimated IP value R 2 720 million
Light utility helicopters: Agusta 109 Power, 40 units, valued at R 2 168 million, estimated IP R 4 685 million
Light fighter Aircraft: Saab Gripen, 28 units, valued at R 10 875 million, estimated IP value R 48 313 million
Trainer Aircraft: BAe Hawk, 24 units, valued at R 4 728 million, estimated IP value R 8 580 million.
Note: IP = industrial participation

Under Remote Control

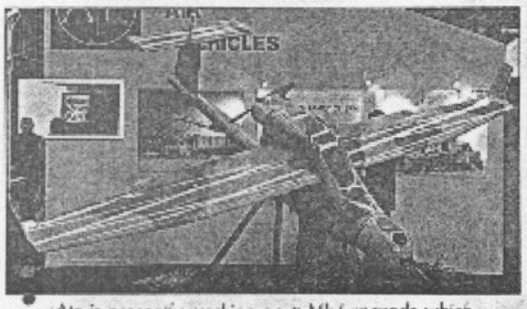
The Ate Vulture made its début at Dexsa as an entire system (a complete launch vehicle being displayed outdoors). First deliveries of this artillery observation drone to the South African Army are due in 1999 for



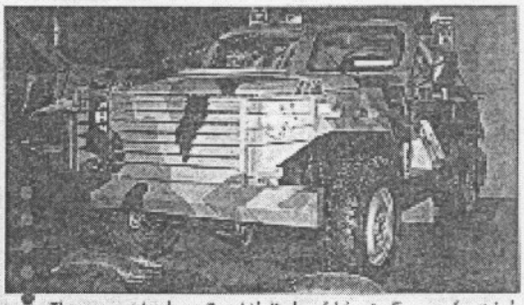
- The new 35DPG corvette mount tips the scales at 5.5 tonnes and has provisions to fire Oerlikon Contraves Ahead munitions.



The Vektor Gama is flexibility itself: by virtue of quick barrel change it fires 12.7 x 99, 20 x 82, 14.5 x 114, 20 x 102 or 20 x 110 HS 404/804 rounds – whether percussion or electrically primed. With 14.5 x 114, the rate of fire can reach 850 rounds per minute.



- Ate is presently working on a Mk I upgrade which would see the current Vulture (featured here) being fitted with wing fuel bladders and flaps. A Mk II and a Super Vulture are additional projects (see text).



- This very Mecbem Bat Mk II should be in France for trials by the time these lines are printed (see text). With a laden weight of 3000 kg, it is nearly capable of carrying its own weight (1800 kg) and can accommodate a 20 mm cannon or a 60 mm mortar, not to mention missile launchers like the Milan.

5) Jane's Defence Upgrade Vol II No.21 (1-15 November 1998)

Subject on Page 3 — South Africa - Vektor's multi calibre GAMA weapon.
Edited — Michael J Gething AMRAeS

an SSN can send and receive while raising only one of its BRA-34 radio masts.

The information received over the USC-38 or USC-42 is downlinked to the submarine's PC-based Battle Group Information Exchange (BGIEX) battle management system – itself another upgrade being fitted on both SSNs and SSBNs. The BGIEX requires the high data rates made possible by the upgraded SSN satellite communications to link with other units of a battle group over the horizon.

Originally designed for surface-ship use, the BGIEX supplements the earlier Submarine Satellite Information System, which has a low transmission rate for receiving VLF/LF messages. The BGIEX is more suitable for the higher rates associated with EHF or UHF transmissions, which the SSN will receive when co-operating with other ships and aircraft in littoral warfare.

Hawkeye looks ahead ... again

While the E-2C Hawkeye airborne early warning (AEW) aircraft prepares for its fourth incarnation (as Hawkeye 2000), Northrop Grumman has revealed its plans for a fifth generation, *writes E R Hooton.*

Beyond Hawkeye 2000, (see *JDU* Vol I, No 12, pp7–8) the company is planning a further upgrade, Hawkeye 2005. This version should achieve initial operating capability between 2008 and 2010. No hardware has yet been assigned to the project, as Northrop Grumman is awaiting the maturation of a number of technologies, the most important being the Surveillance Infrared Search-and-Track (SIRST). This would improve the aircraft's early-warning ability and might allow passive operation using just the SIRST and its electronic support measures (ESM) without active radar transmissions.

Plans exist for improving the AN/APS-145 radar itself, as well as upgrading the ESM and communications systems, together with the installation of a new tactical 'glass' cockpit.

ARMY news

Panhard offer re-engined Sagaie to French Army

BY CHRISTOPHER F FOSS

Panhard, part of the Peugeot Group, has proposed to the French DGA that the French Army upgrades its fleet of Panhard ERC90 F4 Sagaie (6×6) armoured cars (fitted with a Giat Industries 90mm TS-90 turret).

The core of the proposed upgrade is the replacement of the existing Peugeot V-6 petrol engine (developing 132.5hp and coupled to a manual transmission) with a new powerpack. The more fuel-efficient MTU four-cylinder diesel (developing 170hp and coupled to a Rank fully automatic transmission with torque converter) would maintain the vehicle's road speed at 95km/h while increasing operational range from 700km to 900km.

A total of 192 Sagaies were delivered to the French Army between 1984 and 1990, following overseas service in the Middle East and more recently the former Yugoslavia. Today these are the only petrol-engined armoured fighting vehicles in service with the French Army. Like many armies, it is now moving to a common diesel fuel policy with its logistical and increased operational range advantages.

The current vehicle weights 8.3 tonnes and is fully amphibious, propelled in water by waterjets mounted at the rear of the hull. The upgraded vehicle, with add-on armour, weighs 9.5 tonnes but is not amphibious.



Panhard is proposing to upgrade French Sagaie (6×6) armoured cars (here deployed with IFOR in the former Yugoslavia) with a new diesel-based powerpack. *(photo: Richard Strickland).*

If the go-ahead is given next year, at least one prototype will be completed for trials. This will be followed by the award of a production contract, with the first vehicles expected to enter service in 2002.

Since entering French service, the Sagaie has received a number of upgrades. These include additional turret armour; increased external stowage; and a roof skate-mount for a 7.62mm machine gun. Some vehicles have also been fitted with a roof mounted anti-tank missile decoy system.

Export sales of the ERC90 F4 Sagaie and its variants have been made to Argentina (12), Chad (four), Gabon (10), Ivory Coast (seven), Mexico (120) and Nigeria (46). Once it has been type classified by the French Army, the repower upgrade will likewise be offered by Panhard on the export market.

● BELGIUM

Army orders CAM upgrades

Graseby Dynamics of the UK has been awarded a contract worth in excess of £150,000 (US$240,000) to overhaul and upgrade the Chemical Agent Monitors (CAM) used by the Belgian Army and Air Force. This follows on from an existing CAM maintenance contract for the Belgian Navy.

The work, to be spread over two years, involves Graseby in a full maintenance programme, upgrading both hard- and software standards. The software will be upgraded to the latest CAM-plus configuration, which incorporates the ability to detect phosgene chlorine and hydrogen cyanide chemicals plus other toxic industrial chemicals.

● SOUTH AFRICA

Vektor's multi-calibre GAMA cannon

Vektor, a division of South Africa's Denel group, has launched a new version of its 20mm GA1 cannon, known as the Gun Automatic Multiple Ammunition (GAMA), *writes Terry J Gander.*

Primarily in production as a light-aircraft and helicopter weapon – the 20mm GA1 cannon has already undergone several developments. A conversion kit allows the firing of relatively low cost 0.5in (12.7×99mm) Browning ammunition during training, and various alternative vehicle, marine and ground mountings have been introduced. The GAMA introduces further conversion kits, allowing the cannon to interface easily with all existing weapon platforms and mountings. A wide array of ammunition calibres and types enables the cannon to suit varying requirements. Such flexibility in turn extends service life and utility, and spreads potential life cycle costs.

Jane's SPECIAL REPORTS DEFENCE MODERNISATION MARKETS – WESTERN EUROPE

We all know that the modernisation/upgrade market is a growing niche within a declining defence industry but, until now, it has been difficult to quantify.
This Special Report considers all 17 Western European countries – NATO and non-NATO – and looks at every major item of defence equipment, outlining its current status, recent improvements, known modernisation plans and requirements for the next five years. *Can you afford to be without a copy?*

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▶▶▶ The wide selection of calibres is provided by component kits which can be applied to the base GA1 in just over a minute without special skills or tools. These kits cater for both percussion and electrically primed ammunition types, and include components such as the barrel, breech face and feed-related items.

Since the base calibre of the GA1, a design derived from the German Mauser MG151, is 20x82mm, this option is integral in the GAMA. The option of a kit for the Browning training ammunition also remains, with other kits including a 12.7x107mm and 14.5x114mm Eastern Bloc; a 20x102mm M39, electrically primed, for both long and short barrels; and a 20x110mm HS 404.

AIR FORCE news

● UNITED STATES

TACOM takes over two Depots

The US Army's Tank-automotive and Armaments Command (TACOM) assumed responsibilities for two major depots – Anniston Army Depot (Anniston, Alabama) and Red River Army Depot (Texarkana, Texas) – on 1 October, *writes Scott R Gourley.* Both depots formerly reported to the US Army's Industrial Operations Command and have been involved with significant defence upgrade activities in recent years.

TACOM's commanding officer, Major General Roy E Beauchamp, said this realignment of the depots will result in a more direct linkage between TACOM requirements and the production floor.

The Anniston Army Depot maintains and overhauls tracked combat vehicles, their components and small arms, and stores conventional and chemical munitions. Red River Army Depot maintains and overhauls M2/3 Bradley fighting vehicles and the Multiple-Launch Rocket System and stores conventional munitions.

Tthe transfer of responsibility for both depots from IOC to TACOM is a result of the 1997 Quadrennial Defense Review (QDR), sources say. In 1996, Congress passed the Armed Forces Structures Review Act, requiring the Department of Defense to conduct a review every four years. QDR is a comprehensive examination of defence strategy, force structure and modernisation plans, infrastructure, and other elements of the defence programme and policies. Its aim is to determine and express the defence strategy of the United States and establish a revised programme for 2005.

● GREECE

F-4E avioncis well under way

During last month's Defendory exhibition in Athens (see pp7–8), Daimler-Benz Aerospace (Dasa) reported that work is progressing well on the initial Hellenic Air Force F-4E Phantom AUP (Avionics Upgrade Programme) prototype, *writes Michael J Gething.*

Since the arrival of the first F-4E at Dasa's Ottobrun facility in Germany in October 1997, the protoype has been dismantled and a trial retrofit made.

The first flight of the upgraded Phantom is scheduled for next February, with serial retrofits beginning at the Hellenic Aerospace Industry (HAI) at Tanagra in Greece from April. The 39-aircraft programme is contracted to be complete by the end of 2000. (See *JDU*, Vol I No.15, p1)

The Greek Phantom AUP is based on the Luftwaffe's Phantom ICE (Improved Combat Efficiency) programme and incorporates the Raytheon (formerly Hughes) APG-63 radar, the Elbit Modular Multi-Role Computer, and a new inertial navigation system (INS) with an embedded GPS. Additionally, new communications, an IFF transponder, an air data computer, multi-function colour displays, a head-up display and a radio altimeter will be installed.

Once completed, the F-4E AUP will allow the aircraft to use modern air-to-air weapons (including the AIM-120 AMRAAM) and air-to-ground weapons (such as AGM-65 Maverick). The systems removed from the upgraded aircraft will serve as spare parts for non-modified aircraft still flying with the Hellenic Air Force.

● MALTA

Second Islander delivered

The Armed Forces of Malta has taken delivery of its second Britten-Norman Islander. The aircraft has been completely refurbished by the manufacturer at its new Maintenance, Repair and Overhaul facility at Bembridge on the Isle of Wight, UK. The aircraft, a BN2B-26, underwent a refurbishment which included installation of new 260hp Textron Lycoming 0-540-E4C5 engines, new interior trim and seating, and a repaint. It will be used for a wide range of maritime patrol missions, including surveillance of Malta's 25-mile fishing zone and pollution control.

● MOROCCO

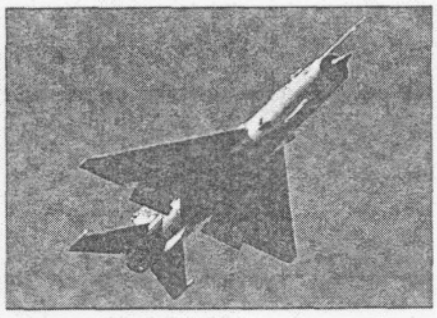
Radar upgrade virtually complete

Northrop Grumman has completed seven out of eight upgrades to the Royal Moroccan Air Force inventory of AN/TPS-63 tactical radars. The two-dimensional, L-band air defence radars have been upgraded with new solid-state transmitters and digital signal processors.

Morocco is the first of nine international customers to take the upgrade to TPS-63(M) configuration. Upgrade kits were delivered in November 1997 and installation has been under way since earlier this year. The final system is due for completion by the year's end.According to the company, this upgrade provides a 250% increase in detection range and significantly enhances reliability, maintainability and logistics support. With a further 67 radars in use by eight other countries, Northrop Grumman is promoting this particular upgrade hard.

Indian MiG-21 upgrade flies

BY MICHAEL J GETHING



The first upgraded MiG-21*bis* for India on its maiden flight. *(photo: Sextant Avionique)*

The first of the 125 MiG-21*bis* 'Fishbed-N' fighters to have been upgraded for the Indian Air Force made its maiden flight from the Nizhny Novgorod air base in Russia on 6 October.

The upgrade, based on the MiG-21-93, was overseen by Russia's MAPO-MIG (Military Industrial Group), designed by the ANPK-MiG design bureau and undertaken by Sokol aircraft production plant at Nizhny Novgorod.

The upgrade features a new navigation and weapons delivery system supplied by Sextant Avionique of France. The new avionics system is built around a 1553 databus and features the Totem ring-laser gyro INS (inertial navigation system). It includes an embedded GPS (global positioning system) which is used as the bus controller as well as providing accurate location and navigation data. A liquid crystal display control and display unit from Sextant is used in the cockpit.

The cockpit also features a head-up display, multi-function displays and HOTAS (hands-on-throttle-and-stick) controls. The radar is replaced with a Kopyo multi-function, pulse-Doppler radar. In addition, a new electronic warfare system – based around a Dassault Electronique (now part of Thomson-CSF) EWS-21 radar warning receiver – is fitted.

The contract was awarded to MAPO-MIG in May 1994 and allowed for two prototype upgrades to be developed in Russia. The first is the single-seat MiG-21*bis* upgrade discussed above; the second is the two-seat MiG-21UM 'Mongol-B' operational conversion trainer.

The remaining 123 aircraft are to be upgraded by HAL (Hindustan Aeronautics Limited) in India, who have manufactured the type under licence in the past. According to *Jane's Aircraft Upgrades*, the cost of this programme is estimated at US$1.33 million per aircraft.

6) Jane's Defence Weekly 25 November 1998

Subject on Page 20 South Africa Augusta A 109s will be equipped with home-grown turrets.

Author Alison Clayton JWD Staff Reporter

MIDDLE EAST/AFRICA

LIW and IST detail export orders



HELMOED-RÖMER HEITMAN *JDW Correspondent*
Cape Town

Two South African companies took the opportunity at DEXSA '98 to detail recent export orders. Denel's LIW division announced an order for a batch of new 20mm armed turrets and upgrades for 90mm turrets from the Irish Army, for its Panhard AML armoured vehicles.

The 20mm turret is a further development of that used in the Ratel-20 infantry fighting vehicle, and is fitted with a third-generation night sight, with video monitors for commander and gunner and an eye-safe laser rangefinder. Eloptro has supplied both subsystems, while the 20mm is LIW's own GI2 20x139mm cannon.

The turret also has an occluded eye gunsight in front of the commander's cupola to serve as a "putter on" or as emergency battle sight. The 90mm turret upgrade pack centres on fitting the same laser rangefinder and night sight. LIW has also developed a new one-man turret which the Irish Army will test for its future armoured personnel carrier (APC). This is a 750kg turret mounting a 12.7mm and a 7.62mm, with 400 and 600 rounds respectively. It has a standard day sight and the same passive night sight as is being fitted to the AML turrets.

Alternative weapon fits include the 20x82mm GA1 cannon with laser rangefinder. A stabilisation system can also be fitted. It provides protection against 20mm ammunition frontally and 12.7mm all-round.

IST Dynamics announced two major export contracts: an order for 30 20mm cannon turrets based on that of the Rooivalk combat helicopter, and another for a remotely-operated twin launcher for the Dragon anti-tank guided weapon (ATGW) for a western European army. IST could not disclose the names of the customers or, in the latter case, the number of launchers.

The Dragon ATGW is a tripod-mounted system that fits two Dragon launchers on either side of a standard sighting unit, and mounts a night sight and an auto-tracker. It allows the gunner to place himself up to 50m away from the launcher.

IST won the order in competition against German, Israeli, Swiss and UK companies. The system has been in development for 20 months, and is due for its troop trials in mid-1999. Some 100 test firings have been carried out to date, with a hit rate of over 90%.

In Brief

LIW will start gun trials soon

Denel's LIW division will conduct firing trials of its prototype twin 35mm Dual Purpose Gun (DPG) using Oerlikon Contraves AHEAD (Advanced Hit Efficiency And Destruction) ammunition at the Alkantpan range in South Africa early next year. Current planning is for the prototype mount, without the adjustments necessary to fire AHEAD ammunition, to be fitted aboard a strike craft in the latter part of next year for sea trials.

Namibia orders Wer'wulf

The Namibian Army has ordered 30 new Wer'wulf Mk 2 mine-protected armoured personnel carriers from Windhoeker Maschinenfabrik (WME). The Mk 2 has an MAN Euro 2 specification 220bhp intercooled turbocharged diesel. WME will also refurbish 30 Wolf Mk 4 mine-protected APCs for Namibia.

Rooivalk makes first public flight

DEXSA's opening ceremony witnessed the inaugural public flight of the first production model of the Rooivalk AH-2A attack helicopter and handing over of the aircraft to the South African Air Force. The first Rooivalk's are due to be delivered to 16 Squadron in Bloemspruit from the beginning of 1999.

Tellumat develops new IFF

Tellumat, the defence company spun off following the reorganisation of Plessey SA, has developed a new Identification Friend or Foe (IFF) system. The PT-2000 gives full mode 1, 2, 3/A and C interrogation and reply, as well as secure Mode 4 or custom national secure mode.

AMS overhead weapons platform

Analysis Management and Systems (AMS) is developing a new servo-controlled overhead weapons platform. It is slaved to the commander's sight and can be used with an auto-tracker. It can mount most machine guns or a 40mm automatic grenade launcher.

LIW 35mm turret upgrade

Denel's LIW division is developing an upgrade for turrets with a 1.5m ring to allow fitting its 35mm externally powered cannon: the cam-driven EMAK. The prototype is being built using a Ratel-90 turret and will mount the cannon with a full day/night fire control system with auto-tracking. The upgrade is targeted at the turrets typically mounted on Panhard AML and Engesa Cascaval armoured cars.

BAT winging its way to French trials

The BAT Mk 2 special forces utility vehicle, manufactured by Denel subsidiary Mechem, was on display at DEXSA '98 before being shipped to France to undergo four months of evaluation for a French Army requirement.

The BAT Mk 2 was expected to be flown out this week to be tested for a French requirement with an in-service date of 1999. There is also a South African requirement which is expected to begin next year but the vehicle will require add-on armour for improved protection.

The new variant of the BAT has been developed to meet the specific French requirement and can be parachute dropped from a maximum of 4,000ft and is transportable by a Cougar utility helicopter. The BAT is already in service with the South African National Defence Force.

Alison Clayton *JDW Staff Reporter*

South African Agusta A 109s will be equipped with home-grown turrets

The Agusta A 109, which the South African government selected as the preferred platform to meet the South African Air Force's (SAAF's) requirement for light-utility helicopters, is likely to be fitted with an indigenous chin-mounted turret and cannon currently under development by IST Dynamics and Denel subsidiary Vektor, respectively.

The IST Dynamics utility helicopter turret system has reduced weight compared to the combat support helicopter variant, about 60kg compared to 175kg, and reduced height, 350mm compared to 875mm. It is also electrically powered as opposed to hydraulic.

First flight of the turret is expected within 12 months and full-scale production within eight months after that. It is unclear whether the turret will be fitted to all 40 A 109s expected to be ordered for the SAAF.

The proposed Vektor Gun Automatic Multiple Ammunition, (GAMA) was shown for the first time at DEXSA '98 and is being marketed as the first weapon system to be able to fire five different calibres: 12.7mm x 99mm; 20mm x 82mm; 14.5mm x 114mm; 20mm x 102mm and 20mm x 110mm HS 404/804.

The GAMA is expected to be qualified in all calibres except 20mm x 102 in the first half of next year and development is also occurring for the system to be able to fire a sixth calibre, 12.7mm x 108mm ammunition. Different calibres are catered for by removing the sleeve, barrel and bolt head with conversion taking place in under 10 minutes. Demonstrations have occurred in Europe and other applications could include ground-to-ground, naval and fixed wing.

Alison Clayton *JDW Staff Reporter*

7) Jane's Defence Upgrade Vol II No. 24 (16-31 December 1998)

Subject on Page 6 Helicopter gun turrets.
Edited Michael J Gething AMRAeS

SHOW *news*

South Africa held its fourth defence exhibition – DEXSA '98 – at the South African Air Force (SAAF) base at Waterkloof from 17–21 November last.

During the show, the selection of many new items of defence equipment was announced. Part of the final deals will involve technology transfer to and licence production in South Africa. While the major platform designs are being bought-in, many systems and equipment will be provided by South Africa's own innovative industry. *Helmoed-Römer Heitman* reports on the upgrade highlights of the show.

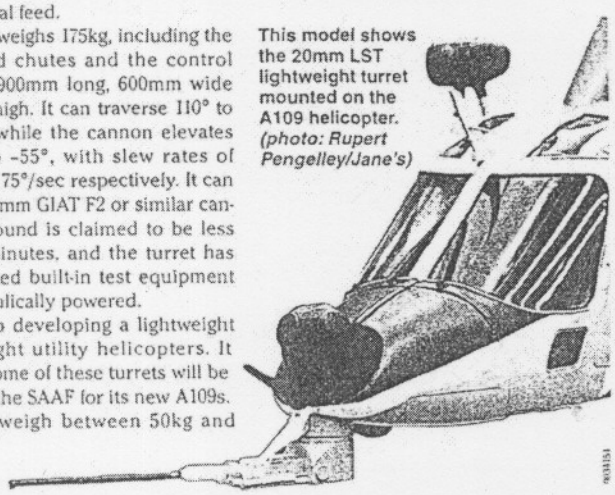
Helicopter gun turrets

LST Dynamics has announced an export order to an undisclosed customer for 30 helicopter gun turrets. The turret is essentially the same as that developed for the Rooivalk and will be armed with a 20mm cannon with selectable dual feed.

The turret weighs 175kg, including the cannon, feed chutes and the control unit, and is 900mm long, 600mm wide and 875mm high. It can traverse 110° to either side, while the cannon elevates from +15° to -55°, with slew rates of 100°/sec and 75°/sec respectively. It can mount the 20mm GIAT F2 or similar cannon. Turnaround is claimed to be less than eight minutes, and the turret has fully integrated built-in test equipment and is hydraulically powered.

LST is also developing a lightweight turret for light utility helicopters. It hopes that some of these turrets will be acquired by the SAAF for its new A109s.

This will weigh between 50kg and 70kg, not including the weapon, and depending on the weapon used. It is 800mm long, 470mm wide and only 350mm high, allowing for the low ground clearance of the A109 aircraft. It is designed to take LIW's new GAMA cannon (see *JDU*, Vol II No 21 p3) or a weapon of similar dimensions and weight. The GAMA can be supplied in 12.7mm, 14.5mm, 20mm×82 and 20mm×102 versions. The turret can traverse 110° to either side of the centreline and the cannon can elevate from +10°to -50°, with slew rages of 80°/sec and 50°/sec respectively.



This model shows the 20mm LST lightweight turret mounted on the A109 helicopter. *(photo: Rupert Pengelley/Jane's)*

ATE Mi-25 upgrade

Advanced Technologies and Engineering (ATE) is developing a low-cost upgrade for the Russian Mil Mi-24/25/35 'Hind' series of attack helicopters. The upgrade is being developed as a 'marketing demonstrator' on the basis of ATE's experience with the Rooivalk. The system is modular to allow a client to match the level of an upgrade to the threat and the available funding.

The overall upgrade package comprises a night-vision goggle (NVG) compatible cockpit, a new day/night sight system, a new 20mm cannon turret and a new anti-tank guided weapon (ATGW) system. ATE has not released details of the sub-systems, but it is likely that most will be derived from those developed for the Rooivalk. A similar package could also be developed for armed Mil Mi-7/17 'Hip' variants.

The decision to develop this was taken to show ATE's capability to upgrade attack helicopters. The upgrade package is being trialled on an Mi-25 which ATE acquired for that purpose. This will also allow potential clients to fine-tune their system on an actual airframe before committing a fleet to conversion.

Tellumat IFF

Tellumat, which was formerly part of Plessey SA, has developed a new IFF (Interrogation, Friend or Foe) Mode S transponder, designated PT-2000. The PT-2000 follows previous IFF systems and provides full Mode 1, 2, 3/A and C interrogation/reply, as well as Secure Mode (Mode 4 or customised national secure mode) with an automatic code changing facility.

It also offers Mode S minimum data-link transponder capability, with a software upgrade to the full Mode S extended length message (ELM) capability. Software and firmware upgrading and access to maintenance information is via a front panel connector.

The unit is a 3/8th ATR box, that has an externally accessible secure mode cryptographic computer. It uses 28V DC power and has no special cooling requirements.

Control and data interfacing is through dual-redundant MIL-STD-1553B or ARINC-429 digital databus. The TCAS computer interface is via a high-speed ARINC-429 link.

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8) Soldiers Fortune - February 1999

Subject on Page 24 The GAMA Solution.
Author Peter G Kokalis

FULL-AUTO

by Peter G. Kokalis

The GAMA Solution

The world's defense markets are generally in what can best be described as a "belt tightening" posture. With the collapse of the Evil Empire at the start of the 1990s, world opinion took a relaxed sigh of relief as the perceived threat seemed to disappear overnight. That this is not really true is apparently of no consequence, since worldwide defense budgets have continued to spiral downward. To survive in this shrinking environment, arms makers must develop and offer products that provide client states with weapon systems that clearly demonstrate substantial cost savings in one area or another.

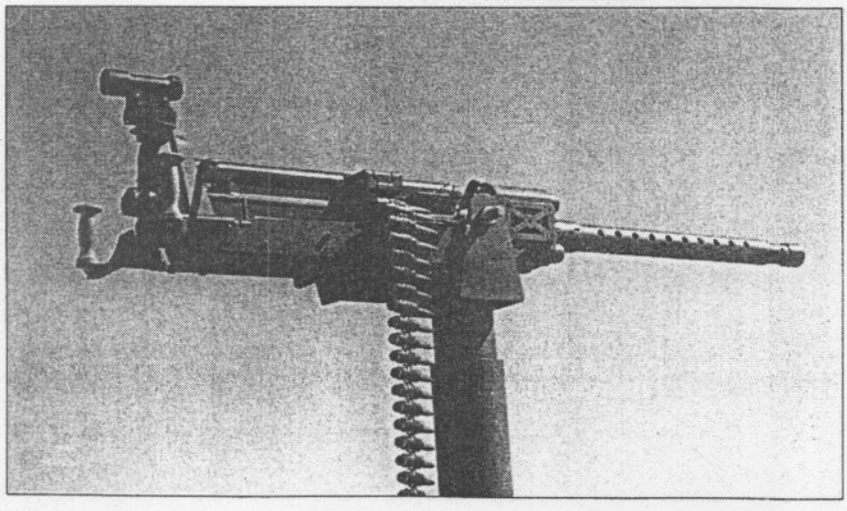
One of the most brilliant examples of this concept is the GAMA (Gun Automatic Multi-Ammunition) project developed by Vektor, a division of Denel (Pty) Ltd. (Dept. SOF, 368 Selbourne Avenue, Lyttelton, Gauteng, P.O. Box 5445, Pretoria 0001, South Africa; phone: 011-27-12-620-2387; fax: 011-27-12-620-2407). The successful objective was to field a 20mm automatic cannon that could be instantly converted to fire more cost-effective smaller caliber ammunition for training, or even other 20mm rounds that a country might already inventory in substantial quantity.

The GAMA system starts with the dependable South African GA1 cannon which is normally chambered for the 20x82mm round. This ammunition is manufactured only in South Africa and to a limited extent in France. Furthermore, some authorities believe that the 20x82mm is marginal in some applications. Research commenced with the 20x110mm Hispano HS-404 shell, which was the longest round anticipated, and was also readily available. The GAMA project envisioned a caliber change to the weapon only, not the entire gun pod. The mounting points thus would remain the same.

The GA1 itself is a vastly improved and updated version of the German MG 151/20 aircraft cannon, which was designed in 1934 as a 15mm weapon but was scaled up to 20mm during World War II at the request of the *Luftwaffe*. The MG 151/20 was also adopted by the Japanese and used as a "flexible" gun in bombers. Subsequent to World War II, it was employed by the French air force.

The method of operation is roller-locked short-recoil with firing from the open-bolt position. The cyclic rate is 650 to 750 rpm. Belt-fed, the GA1 uses push-through disintegrating steel links. The headspace is fixed. The bolt is a two-piece assembly with three lugs on the bolt head (similar in appearance to interrupted threads) that rotate slightly more than 57 degrees clockwise to lock within recesses in a receiver bushing. The bolt head also contains the two locking rollers, which run on cam tracks in an unlocking ring inside the receiver body.





(right) GA1 automatic cannon chambered for the 20x82mm round, mounted in tandem with an SS77 GPMG in caliber 7.62x51mm NATO, on a South African Buffel, a mine-protected personnel carrier. (below) GA1 converted to fire the 12.7x99mm (.50 cal. Browning) heavy machine gun round.

The front end of the receiver bushing holds the barrel by means of interrupted threads. A spring-loaded, anti-bounce device that consists of a steel balance weight with a multi-strand spring — both riding inside the bolt carrier — serves as a stabilizer for the reciprocating components. There is a heavy compression spring between the receiver bushing and the unlocking ring. When the barrel moves rearward in recoil, it drives the bolt head rearward against the cams on the unlocking ring to rotate the bolt anti-clockwise out of battery. A multi-strand spring buffer at the rear of the receiver absorbs some of the systems recoil energy.

The principal distinction between heavy machine guns and automatic cannons lies in the area of their ammunition. There is often very little difference between their cases. Propellants and charge weights also differ very little. The primer caps on ammunition designed for automatic cannons may be of either

the percussion or electrical types.

The greatest difference between heavy machine guns and cannon ammunition is therefore in their respective projectile types. Most cannon projectiles are shells (i.e., hollow projectiles which contain explosive material that is initiated by an impact fuze at the target or at some earlier point during the trajectory by a time-delay mechanism). Most, but not all, heavy machine-gun projectiles are of the solid-ball type with lead or steel cores, which sometimes have hollowed-out areas at the base or nose that contain tracer or incendiary elements, respectively.

The GAMA project objective was to provide for conversion to six calibers. In addition to the original 20x82mm, they are the 20x102mm (US M39, most often electrically primed) and 20x110mm cannon rounds and the following heavy machine gun cartridges: 12.7x99mm (.50 cal. Browning), 12.7x108mm (Russian) and 14.5x114mm (also Russian). The US 20x102mm is considerably more powerful than the 20x110mm, with a muzzle velocity close to that of the 20x139mm Hispano. The design challenge was the longer overall length of the 20x110mm round and the larger rim diameter of the US 20x102mm cartridge (29.5 mm versus 25.1 mm for the 20x82mm. At first a telescoping bolt carrier was tried, but eventually the receiver was lengthened. The larger rim diameter required the feed mechanism to be lifted. The same link, with plastic inserts for the smaller calibers, was used for all six calibers. The original GA1 cyclic rate, 650 to 750 rpm, was retained for all calibers.

The following changes were made to the GA1: 1) The receiver body was lengthened and is 72 mm longer than the original. 2) To get the bolt head behind the longest round (20x110mm), the feed tray was lengthened by 36 mm. There are spacers for use with shorter rounds. 3) The cartridge stop was also lengthened by 36 mm and thus the pick-up point, where rounds are stripped from the links, remains the same for all calibers. 4) The bolt carrier was also lengthened by 36 mm. 5) The top cover was also lengthened by 36 mm at the front end to move the feed mechanism backward in position over the links. 6) The bullet lead (guide) was modified. 7) The buffer assembly was redesigned and the barrel spring removed. 8) And, of course, each caliber has its own barrel. The barrels for higher energy rounds have muzzle breaks designed by mathematical modeling. With regard to the electrically-primed US 20x102mm case, the round is fully chambered before the electric impulse strikes the primer. This method of discharge is also employed in Vektor's 30mm DEFA 55C5 cannon.

Muzzle velocities of the various conversion rounds vary considerably. The South African 20x82mm cannon shell leaves the muzzle at 2,362 fps, while the 20x110mm round reaches 2,723 fps. Both the US 20x102mm cartridge and the Russian 14.5x114 heavy machine gun round have a muzzle velocity of 3,380 fps.

The GAMA design forecast was done using dynamic motion analysis. Structural behavior was examined by means of finite element analysis. And, the entire system was designed by CAD (Computer Aided Design).

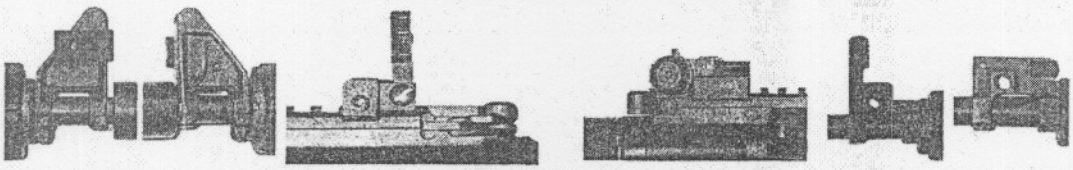
I have personally witnessed the GA1 — mounted on the Caspir Mk 2 Mine Protected Vehicle (MPV) — employed with deadly effect by *Koevoet* (a police counterinsurgency unit) in the former South West Africa (now Namibia) on the border with Angola.

It's salient features are the simplicity of its design, which provides for ease of maintenance and cleaning, its compactness and a relatively light weight. With a 20x82mm barrel, but without a mount, the GA1 weighs only 39 kilograms (approximately 86 pounds), empty. This compares with 84 pounds for the .50 caliber Browning M2 HB machine gun and with 106.5 pounds for the caliber 12.7x108mm Russian *Degtyarev Pekhotnyy* (DP) Model 38/46 heavy machine gun.

The GAMA project adds even further versatility to what is without question one of the finest 20mm automatic cannons in the world. The GA1 can be mounted on a tripod, in an aircraft pod, or on mounts designed for helicopters, boats or vehicles.

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9) Beeld Tuesday 27 April 1999 - SANDF, Annexure

Subject on Page 12 GAMA (Gun Automatic Multiple Ammunition).
Author -

t Beeld Dinsdag 27 April 1999

LTYD IN DIE KOL MET VEKTOR

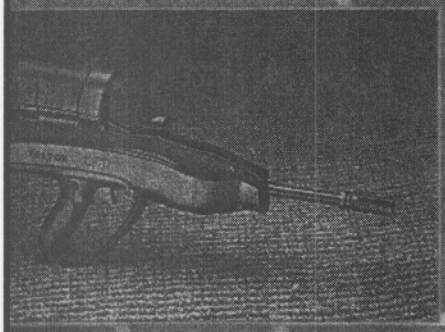
LIW (Lyttelton Ingenieurswerke) gestig. Sedert aparte afdeling van Denel. Die Maatskappy is trots sei wat gekoppel word aan die internasionale ISO or het plaaslik en internasionaal 'n reputasie op- e van hoë gehalte.

in die vervaardiging en bemarking van gevegs- waaronder semi-outomatiese vuurwapens, meer- masjiengewere, mortierstelsels en outomatiese gewere.

aan die SANW tegnologies gevorderde wapen- els op die internasionale mark oortref.

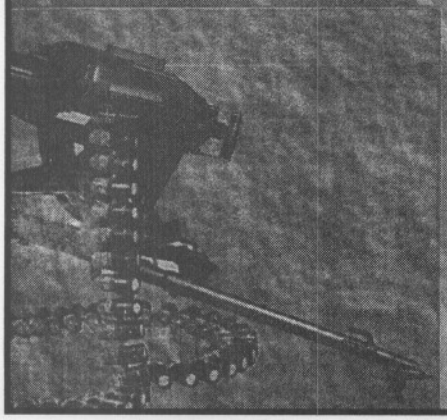
oë kwaliteit betroubare produkte, het Vektor nog die SANW en die SAPD gehandhaaf en emeem om nuwe hoëtegnologiewapenstelsels te aronder die CR 21, 40 mm OGL Outomatiese (Gun Automatic Multiple Ammunition).

EER



die welbekende R4-, R5- en R6-stormgewere wat n Spesiale Magte gebruik word. Vektor en die valuering van die CR 21-stormgeweer afgehandel. R4, R5 en R6. Die CR 21 is 'n goed gebalanseerde, ulloup'-ontwerp van die allermodernste sintetiese e voorkoms van die wapen afrond. Die optiese merk en het die waarskynlikheid dat 'n gemiddelde ste skoot sal tref met meer as 44% verhoog.

GRANAATLANSEERDER (OGL)



PISTOLE

Vektor is ook die vervaardiger van die welbekende Z88-pistool wat tans deur die SAPD gebruik word. Aangesien die Maatskappy streef na die vervaardiging van produkte wat in kliëntbehoeftes voorsien, het hy die SP- (Dienspistool) en CP- (Kompakte Pistool) families by sy pistoolreeks gevoeg, wat ook die sportprodukreeks insluit. Vektor het onlangs die SP Generaalsmodel ontwerp en begin vervaardig. Die Generaalsmodel kom voor in 9 mm of .40 S&W, beskik oor dubbelaksie en is meer kompak as die standaard SP-pistool.

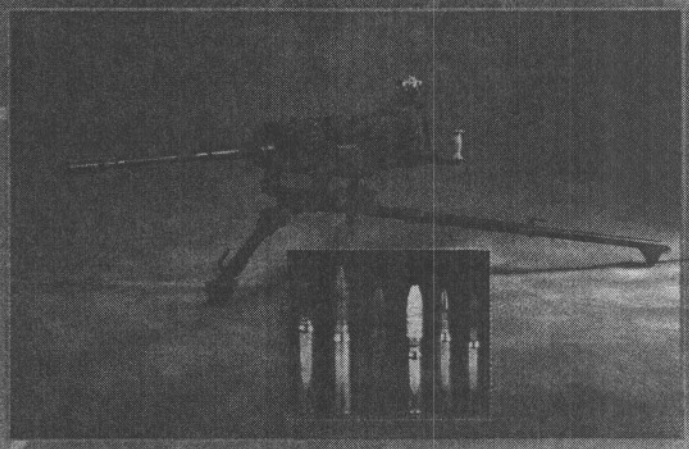
MASJIENGEWERE

Vektor vervaardig ook die SS77 en die MINI SS meerdoelige masjiengeweer. Die stelsels maak gebruik van onderskeidelik 7.62 mm- en 5.56 mm-ammunisie. Dit is die mees moderne, gevegsbeproefde, ligte masjiengeweer in die wêreld. Die SS77- en die MINI SS-ontwerpe beskik oor 'n kombinasie van die kenmerke van die beste masjiengewere ter wêreld. 'n Omskakelingstel is ook beskikbaar om die SS77 te omskep om 5.56 mm-ammunisie af te vuur. Die SS77 en die MINI SS is ongekompliseerde, betroubare wapenstelsels wat maklik hanteer en in stand gehou kan word.

SNELVUURKANONNE

Vektor vervaardig ook die 20 mm GA 1 outomatiese kanon wat 'n uiters betroubare, kompakte, liggewigkanon is wat maklik in stand gehou word. Die wapen kan op vlegtuie en gevegsvoertuie van die infanterie gebruik word. Die wapen beskik oor 'n omskakelingstel om 12.7 mm-ammunisie af te vuur wat tydens oefensessies gebruik kan word en sodoende help om opleidingskoste te verlaag. Verder vervaardig hulle ook die 20 mm GI-2 outomatiese kanon met 'n vernietigende trefkrag. Die dubbelvoergaskanon is uiters geskik vir gebruik op gevegsvoertuie van die infanterie, maar word ook op groter helikopters, skepe en ander ligte voertuie gebruik.

GAMA (GUN AUTOMATIC MULTIPLE AMMUNITION)



Tydens die DEXSA '98 uitstalling wat in middel November 1998 by die Waterkloof Lugmagbasis in Pretoria gehou is, het Vektor 'n nuwe kanontipe wapenstelsel, bekend as die GAMA (Gun Automatic Multiple Ammunition), bekend gestel. Dit is die eerste kanon in sy soort wat aan die wêreld bekend gestel is. Vektor het die moeilike, indien nie die onmoontlike, reggekry, naamlik om verskillende kalibers in een wapenstelsel te akkommodeer. Dit kan tans vyf (5) verskillende kalibers, nl 12.7 x 99, 20 x 82, 14.5 x 114, 20 x 102 en 20 x 110 HS 404/804 afvuur en aansienlike vordering is met die akommodering van 12.7 x 108-ammunisie gemaak. Dit is die kalibers wat deesdae wêreldwyd gebruik word. Die GAMA wapenstelsel is uiters geskik vir diens tydens vredesoperasies aangesien die toepaslike kaliber na gelang van behoefte gebruik kan word.

MORTIERE

'n Deel van Vektor se produkreeks is die mortierstelsels soos die 60 mm-patrollie-mortier, 60 mm en 81 mm wat met lang- en standaard reikafstand kan voorkom

10) Jane's Infantry Weapons Twenty Sixth Edition 2001 – 2002

Subject on Page 366 South Africa - Vektor Gun Automatic Multiple Ammunition (GAMA).
Edited Terry J Gander

Vektor 20 mm GA1 cannon

Description

The Vektor 20 mm GA1 cannon is chambered for 20 × 82 mm ammunition and was developed primarily as a relatively lightweight, multi-purpose automatic cannon for air, land and marine applications.

The GA1 is a gas-assisted blowback weapon. Firing from an open breech, the bolt is locked in place by two side flaps; after firing, gas pressure drives two pistons back to rotate these flaps and unlock the bolt, after which residual chamber pressure forces the bolt backwards to complete the functioning cycle. There is a dual feed facility, with ammunition feed possible from the left or right. Firing may be manual or electrical.

For aiming, the Armson Occluded Eye red dot gunsight is recommended, although other optical sights can be used to suit customer requirements.

Ammunition types available include HEI, HEI-T, SAPHEI, APC, TP and TP-T. Muzzle velocity is 720 m/s.

Vektor-produced mountings for the GA1 include the Vektor CVM20 for the Casspir APC or other vehicles, the GVM20 Gemini vehicle mount with one GA1 cannon located over the other, the AP20 fixed wing gunpod, a helicopter mount, the SMM20 single marine mount and the GMM20 Gemini twin marine mount. A ground tripod mounting for use by infantry is under consideration.

Vektor have developed a conversion kit to provide relatively low-cost training by permitting the GA1 to fire 12.7 × 99 mm (0.50 Browning) ammunition at a cyclic rate of 500 to 600 rds/min. The conversion can be accomplished within minutes without recourse to tools and involves only a few components, such as changing the barrel and bolt head and adding a feed plate and barrel jacket, and the introduction of ammunition link adaptors.

Variant

20 mm Gama cannon
See following entry.

Specifications

Cartridge: 20 × 82 mm
Operation: gas-assisted blowback
Locking: flaps
Feed: disintegrating link belts. left- or right-hand feed
Weight: weapon assembly with barrel, 39 kg; barrel, 10 kg
Length: 1.77 m
Barrel: 1.102 m
Rifling: 8 grooves, rh
Muzzle velocity: 720 m/s
Rate of fire: cyclic, 650-750 rds/min
Recoil force: 3,500 N
Power requirement: 22-29 V DC

Manufacturer

Vektor, a division of Denel (Pty) Ltd, 368 Selborne Avenue, Lyttleton, PO Box 5445, Pretoria 0001.

Status

In production.

Service

South African National Defence Force.

VERIFIED

Vektor Gun Automatic Multiple Ammunition (GAMA)

Development

While the Vektor 20 mm GA1 cannon (see previous entry) has the facility to utilise low cost 12.7/0.50 Browning ammunition for training or other purposes, Vektor have decided to expand this capability still further by further modifying the concept into the Gun Automatic Multiple Ammunition (GAMA). This is capable of allowing the one base cannon, the GA1, to accommodate a variety of ammunition calibres and types with a minimum of associated components and conversion time. According to Vektor, this allows all calibre conversions to interface with existing weapon platforms and permits weapon upgrades with minimum cost. The concept also offers considerable weapon life cycle cost reductions and can considerably expand the service lives of existing in-service weapons. In addition, local ammunition supplies can be readily utilised by rapid deployment forces.

Description

The Vektor GAMA is based on the 20 mm GA1 cannon and has been developed to the stage where it can be converted to fire the following types of ammunition:

Calibre	Weight	MV	Rate of fire
12.7 × 99 mm	47 kg	820 m/s	500-600 rds/min
12.7 × 107 mm	47 kg	840 m/s	n/av*
14.5 × 114 mm	50 kg	1,030 m/s	750-850 rds/min
20 × 82 mm	48 kg	720 m/s	600-700 rds/min
20 × 102 mm (short barrel)	50 kg	1,030 m/s	700-800 rds/min
20 × 102 mm (long barrel)	55 kg	1,030 m/s	700-800 rds/min
20 × 110 mm	53 kg	850 m/s	600-700 rds/min

*To be determined

20 × 82 mm (the base GA1 calibre)
12.7 × 99 mm (0.50 Browning)
12.7 × 107 mm
14.5 × 114 mm
20 × 102 mm
20 × 110 mm

The conversion of an existing cannon to a new calibre involves only the calibre-sensitive components such as the barrel, breech block or bolt face, barrel sleeve, feed pawls and so on. A conversion can be carried out in the field in as little as 10 minutes without recourse to special tools or skills. The actual number and type of components will vary from calibre to calibre.

Basic details of the calibres involved with the GAMA to date include the table.

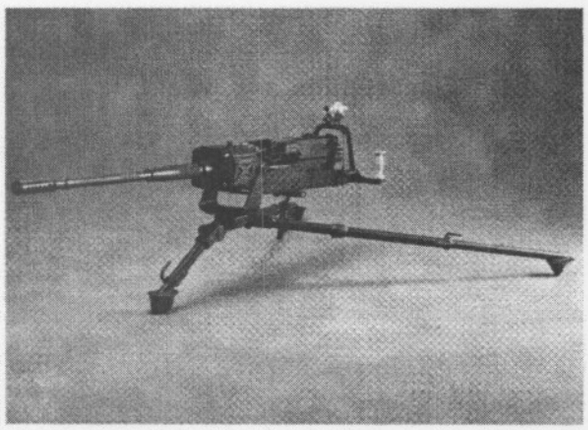
Manufacturer

Vektor, a division of Denel (Pty) Ltd, 368 Selborne Avenue, Lyttleton, PO Box 5445, Pretoria 0001.

Status

Qualification of the weapon in 20 × 110 mm, 14.5 × 114 mm, 20 × 82 mm and 12.7 × 99 mm scheduled for the first half of 1999.

UPDATED



Tripod-mounted Vektor Gun Automatic Multiple Ammunition (GAMA) **2000**/0063257



Vektor Gun Automatic Multiple Ammunition (GAMA) showing the various barrels available
2000/0063258

11) Amendments and Additional Notes to "Rapid Fire"

Updated - 17 April 2005

AMENDMENTS AND ADDITIONAL NOTES TO "RAPID FIRE"
... calibres. The gun is known as the GAMA (**Gun Automatic Multiple Ammunition**) and is based on the GA-1 (aka Mauser MG 151/20). Calibres ...
quarry.nildram.co.uk/~autogun/corrections.html - 99k - Supplemental Result - Cached - Similar pages

Web Address -
http://quarry.nildram.co.uk/~autogun/corrections.html

Extraction -
Page 101

The South African firm of Vektor is developing a family of weapons based on the same design but available in different calibres. The gun is known as the GAMA (Gun Automatic Multiple Ammunition) and is based on the GA-1 (aka Mauser MG 151/20). Calibres planned so far are as follows 12.7x99, 12.7x108, 14.5x114, 20x82, 20x102, 20x110. Weights range from 47 to 55 kg, and RoFs from 500-600 rpm (12.7x99) to 750-850 rpm (14.5x114). Since the 23x115 is just the 14.5x114 necked-out, it makes you wonder why they don't offer that as well! This is an interesting reminder of the WW2 American T17 project, which consisted of adapting the MG 151 to fire the .60 anti-tank ammunition (the cartridge case for which was subsequently necked out to create the 20x102).

12) Publication (Foreign Language) GAMA - Kulomet, Nebo Kanón

[PDF] Skupina bibliograficko-informační činnosti Knihovny PA ČR vydává ...
File Format PDF/Adobe Acrobat - View as HTML
Denel Ltd., představeným v r. 1998. Umožňuje střílet šesti druhy munice tří různých. ráží, odtud také zkratka GAMA - **Gun Automatic Multiple Ammunition**. ...
www.polac.cz/knihovna/dz0506.pdf - Similar pages

Web Address -
http://www.polac.cz/knihovna/dz0506.pdf

Extraction -
GAMA - kulomet, nebo kanón?
In Střelecká revue. - 37, 2005, č. 3, s. 19.
25
Popis zajímavého zbraňového hybridu GAMA, u kterého nelze jednoznačně říci, zda se jedná o kulomet nebo kanón. Uvedená zbraň je výrobkem jihoafrické zbrojní firmy Denel Ltd., představeným v r. 1998. Umožňuje střílet šesti druhy munice tří různých ráží, odtud také zkratka GAMA - Gun Automatic Multiple Ammunition.
CZ - cze PA če/2005
002024 - ANAL 034268
HRADECKÝ, Martin

13) Vernick Aviation – Land Based Air Defence Glossary

Venik's Aviation - Land-Based Air Defense Glossary
GAMA, **Gun Automatic Multiple Ammunition**. GCU, Gun Control Unit. GMG, General Machine
Gun. GPMC, General Purpose Machine Gun. GPS, Global Positioning System **...**
www.aeronautics.ru/archive/reference/ Land_Based_Air_Defense_Glossary.htm - 138k - Cached - Similar pages

Web Address -
http //www.aeronautics.ru/index.htm http //www.aeronautics.ru/archive/reference/Land_Based_Air_Defense_Glossary.htm

Extraction -

Land-Based Air Defense Glossary	
Term	**Definition**
FRAG	Fragmentation
FTA	Frangible Training Ammunition
FTT	Field Tactical Trainer
FV	Fighting Vehicle
FY	Fiscal Year
g	Gramme(s)
GAMA	Gun Automatic Multiple Ammunition
GCU	Gun Control Unit
GMG	General Machine Gun
GPMC	General Purpose Machine Gun

14) Vernick Aviation – Infantry Weapons Glossary

Venik's Aviation - Infantry Weapons Glossary
GAMA, **Gun Automatic Multiple Ammunition**. GBAD, Ground Based Air Defence. GCU,
Gun Control Unit. GL, Grenade Launcher. GLDNSM, Grenade Launcher Day-Night **...**
www.aeronautics.ru/archive/ reference/Infantry_Weapons_Glossary.htm - 171k - Cached - Similar pages
[More results from www.aeronautics.ru]

Web Address -
http //www.aeronautics.ru/archive/reference/Infantry_Weapons_Glossary.htm

15) 20mm Ammunition

20mm Ammunition, 20mm Ammunition spot
... 20mm Vektor GAMA. Notes The GAMA (**Gun Automatic Multiple Ammunition**) is a variant ...
http //pmulcahy.100megs3.com/autocannons/south_afric... 22. **...**

www.ammoammunition.com/4/20mmammunition/ - 23k - Supplemental Result - Cached - Similar pages

Web Address -
http_//www.ammoamunition.com/4/20mmammunition/

16) South Africa Automatic Cannons

South African Autocannons
Notes The GAMA (**Gun Automatic Multiple Ammunition**) is a variant of the GA1 that
employs a series of interchangeable barrels and feed mechanisms to fire a **...**
www.pmulcahy.com/autocannons/ south_african_autocannons.html - 39k - Cached - Similar pages

Web Address -
http_//www.pmulcahy.com/autocannons/south_african_autocannons.html

Extraction -

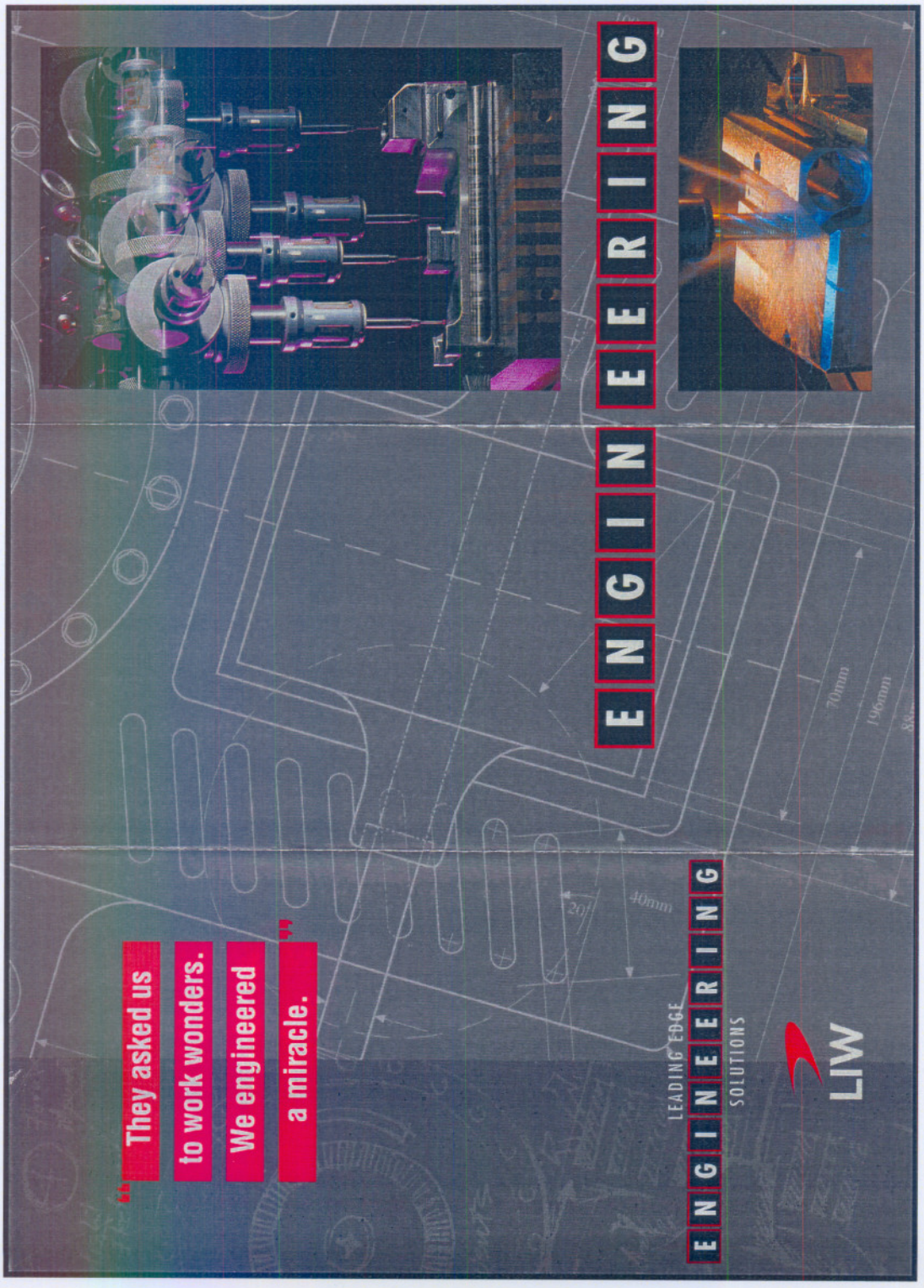
20mm Vektor GAMA

Notes The GAMA (Gun Automatic Multiple Ammunition) is a variant of the GA1 that employs a series of interchangeable barrels and feed mechanisms to fire a large amount of ammunition types. The weapon is issued as a kit containing the barrels and receiver groups. It was first developed to allow the user to train with cheaper smaller caliber ammunition, but was then further developed to give the user greater utility with the weapon.

E. PUBLICATIONS RELATED TO THE PROCESS

3D Developmental analysis has now been introduced using Finite Element Analysis and Motion Analysis. The quantum leap in development was so phenomenal that LIW and DENEL engaged in the full scale marketing of this new innovation. It also contributed to the fact that LIW was honoured to be the Company of the Year 1993.

1) LIW Marketing Pamphlet

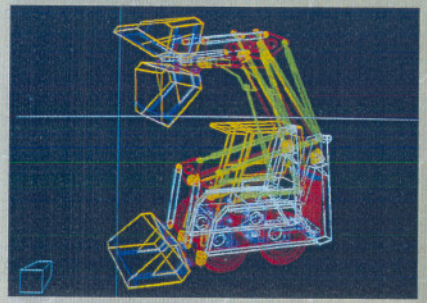


DESIGN AND DEVELOPMENT

The idea may be a product. It may be an exploration of a latent requirement for a product. It may even be a request to reverse engineer an existing product.

We endeavour to identify and define the clients' exact requirements and needs, using a method of Simultaneous Development with the following salient features:

- Design is developed as analysis is done on functions and interactions, which is then related to physical hardware.
- With the aid of CAD the necessary volumes, mass, physical interfaces, geometry and inertias are determined.
- Static finite element analysis is done to determine stress distribution, deflections, temperature distribution etc.
- Dynamic finite element analysis is done to predict natural frequencies and mode shapes in components or structures.
- Dynamic analysis is done to predict displacements, velocities and acceleration of components



Sophisticated CAD – the backbone of our design systems.



Finite element component analysis

MANUFACTURING

MACHINING

High precision machining is carried out on conventional and/or CNC machines which is further enhanced by the following:

- Process design which ensures that the manufacturing process followed will result in components of consistent quality.
- NC programming
- Tools, gauges and fixture design is carried out for the manufacturing process chosen.
- Modern toolroom facilities undertake the manufacture of the fixtures and gauges as well as the sharpening and reconditioning of the required cutting tools.

If you have an innovative ide

LIW

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366 Selborne Avenue Lyttelton
P O Box 7710 Pretoria 0001
Telephone (012) 6202387
Fax (012) 6202283

A Pentagraph Design

2) DENEL Marketing Pamphlet



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Railway warning signals
These detonators have been specially designed for use by Transnet as warning signals for trains and railway workers.



High speed photography services
OTB provides a skilled high speed photography service for slow motion effects in commercial, feature and industrial film applications. A 35mm-4E Photosonic high speed camera with pin-registration, 360 fps and full reflex viewing is used. Standard lenses can be used on the camera.



Slag buster kiln gun
The slag buster is tough and rugged and able to operate in the hottest kilns to blast away slag build-up without having to down the kiln.



Contract production and assembly
Irenco offers globally competitive:
- Procurement
- Electronic assembly
  - SMT and conventional
  - Looms and cables
  - Mechanical assembly
- Testing and Burn-in
- Plastic injection moulding

INDUSTRIAL



Manufacturing management system
This integrated system provides for a variety of manufacturing environments including configure to order, make to order, make to forecast, and make to stock. It can be used for discrete, process, and repetitive production. It is structured to support manufacturing strategies like Group Technology, Parallel Engineering (Development), Total Quality Control, Just-In-Time, and Computer Integrated Manufacturing. Management information which enables long term objective development, supporting strategy implementation, and tactical operations monitoring, is also provided.

3) Engineering Week Report February 1994



Engineering WEEK
REPORT
February 1994

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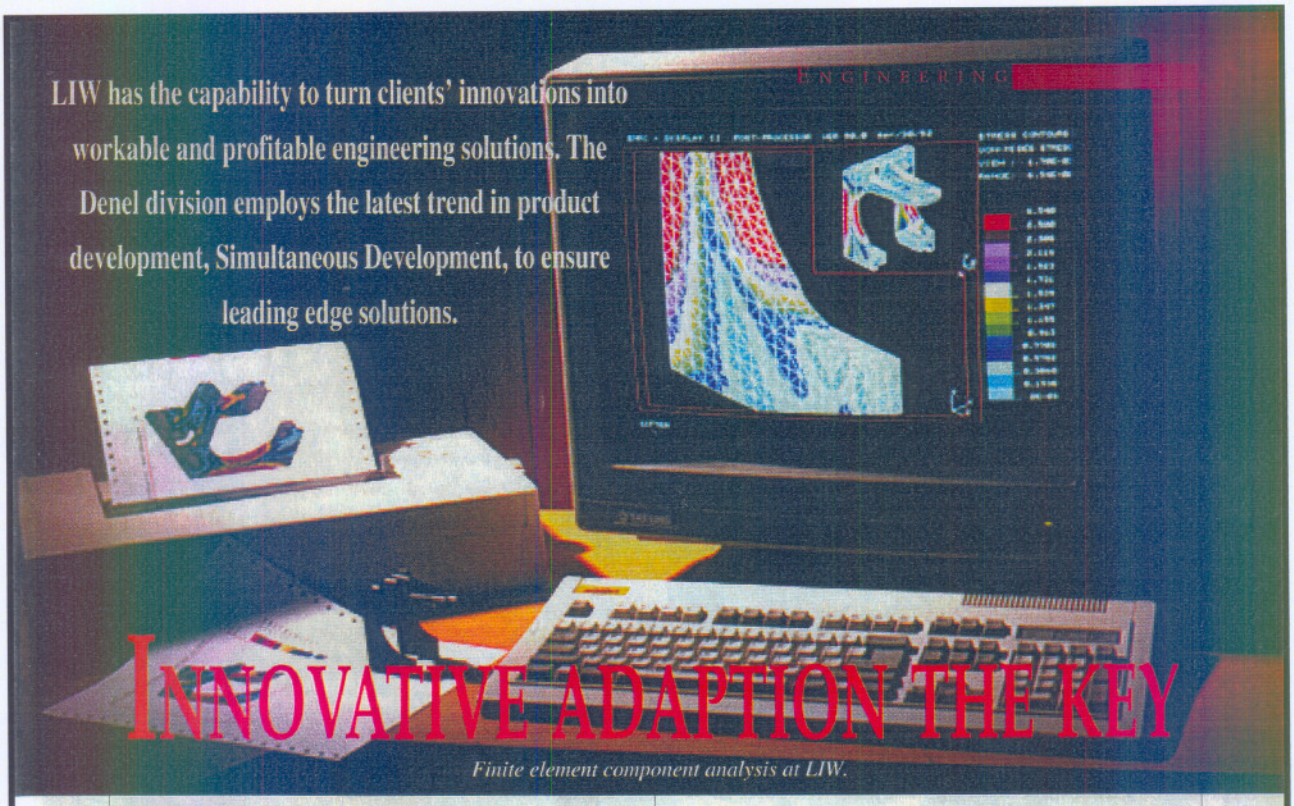
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LIW has the capability to turn clients' innovations into workable and profitable engineering solutions. The Denel division employs the latest trend in product development, Simultaneous Development, to ensure leading edge solutions.



INNOVATIVE ADAPTION THE KEY

Finite element component analysis at LIW.

LIW's mainstay over the years has been its capacity for innovation, adaption and high-tech product evaluation and there is growing recognition throughout South African industry that these are the qualities required if it is to grow and be competitive in the decades to come.

Comments assistant general manager - Vektor Business Unit Thys Cronje: "Our work in the design and development of high-tech armaments has been internationally recognised and enables us to help our clients turn their innovations into workable and profitable engineering solutions.

"This may involve the actual design of a new product, the exploration of a latent requirement of an existing product, or even the reverse engineering of the latter."

Experience has shown that the eventual success of a project hinges on its design reflecting the client's exact requirements and LIW employs the latest trend in product development, Simultaneous Development (where design is developed as analysis is done on functions), to ensure leading edge solutions.

Continues Cronje: "After identifying a need, the required functions are analysed by means of a functional breakdown to determine the lower levels of system functions and their interaction in product performance."

Once synergy has been achieved, the functions can then be related to physical hardware and synthesis of the product volumes, physical interfaces and geometry can be designed and integrated.

Before the manufacture of a prototype can commence the critical components and characteristics are identified for theoretical modelling.

This stage of product development involves the calculation, in real time, of critical masses, inertias and stresses of components or assemblies through Computer Aided Engineering which includes:

* Static Finite Element Analysis (FEM) for the determination of stress distribution, deflections or temperature distribution.
* Dynamic Finite Element Analysis for the prediction of natural frequencies and mode shapes in components or structures.
* Dynamic modelling and analysis for the prediction of displacement, velocities and acceleration of components in a mechanism.

Says Cronje: "The results of these analyses enable us to revise the product's design - if necessary - before beginning hardware manufacture.

"Once the hardware has been built the important characteristics like masses, inertias, stresses and deflection displacements, frequencies and mode shapes, displacements and acceleration are confirmed.

"The design is further optimised by assimilating the test results and implementing modifications to the design, computer models or test procedures where necessary."

To summarise, it can be seen that LIW's Simultaneous Development design process allows it to revise elements of design on the basis of current analyses before proceeding with the manufacture of the hardware.

Once the modelling is complete and the designer assured that all product or system requirements have been met, the resultant data pack is then related to physical hardware.

Explains Cronje: "At this stage we have achieved the elegant design upon which the solution to our client's engineering problem will depend."

F. TYPICAL FINITE ELEMENT ANALYSIS LIBRARIES

1) Nastran Element Library

Element Type	Element Name	Description
Scalar	ELAS	Scalar spring (several variations)
	MASS	Scalar Mass (several variations)
1D	BAR	Simple beam element
	BEAM	Complex beam element including shear center offset and variable cross section
	BEND	Curved beam, pipe, or elbow
	ROD, CONROD	Rod element
	TUBE	Tension-compression-torsion element
2D	QUAD4	Quadrilateral plate with membrane-bending or plane strain behavior
	QUAD8	Higher-order quadrilateral shell element
	QUADR	Quadrilateral membrane or shell
	SHEAR	Shear panel
	TRIA3	Triangular plate with membraine-bending or plain strain behavior
	TRIA6	Higher-order triangular shell element
	TRIAR	Triangular membrane or shell
3D	HEXA	Six-sided solid element with 8-20 grid points
	PENTA	Five-sided solid element with 6-15 grid points
	TETRA	Four-sided solid element with 4-10 grid points
Rigid	RBAR	Rigid bar element
	RBE1	Rigid body connected to an arbitrary number of grid points
	RBE2	Rigid body with independent DOFs at a grid point and dependent DOFs at an arbitrary number of grid points
	RROD	Pin-ended rigid rod
	RTRPLT	Rigid triangular plate
Interpolation	RBE3	Defines the motion of a reference point as the weighted average of the motions at a set of other grid points
	RSPLINE	Multipoint constraints for the interpolation of displacements at grid points
Composites	BEAM	Complex beam element
	QUAD4	Quadrilateral plate
	QUAD8	Higher-order quadrilateral plate
	TRIA3	Triangular plate
	TRIA6	Higher order triangular plate
p-Elements	HEXA	Six-sided solid element with 8-20 grid points
	PENTA	Five sided solid element with 6-15 grid points
	TETRA	Four-sided solid element with 4-10 grid points
Axisymmetric	CONEAX	Conical shell
	TRIAX6	Triangular cross section ring
Crack Tip	CRAC2D	Two-dimensional crack tip element
	CRAC3D	Three-dimensional crack tip element
General	CONM1	6-by-6 symmetric mass matrix
	CONM2	Concentrated mass with offsets
	DMI	Direct matrix input
	GENEL	General element

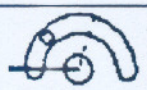
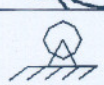
2) Nastran Load Application Library

Load Type	Load Name	Description
Point	FORCE MOMENT	Concentrated force (several variations) Concentrated moment (several variations)
Curve	GMLOAD PLOAD1	Load distributed along a geometric curve Concentrated, uniform, or linear load applied to 1D elements
Surface	GMLOAD PLOAD	Load distributed along a geometric surface Pressure load applied to 2D elements or the face of 3D elements (several variations)
Volume	GRAV RFORCE	Steady-state acceleration vectors Angular velocity or acceleration
Enforced Motion	GMBC GMSPC SPC	Enforced displacements for geometry (curves and surfaces) Constraints applied to geometry Constraints applied to grid points (several variations)
Thermal	TEMP TEMPP1 TEMPRB	Temperatures applied to grid points (several variations) 2D element temperature field 1D element temperature field
Axisymmetric	FORCEAX MOMAX PLOAD1X PRESAX SPCAX TEMPAX	Concentrated force Concentrated moment Surface traction Pressure loading Constraints Applied temperatures
General	DMI	Direct matrix input
Combination	LOAD	Combines load sets

G. TYPICAL MOTION ANALYSIS LIBRARIES

1) Mechanica Motion Toolbox – Connectivity Library

Mechanica prior to the use of Adams was used to assemble and analyse the motional behaviour of the GA1 and GAMA.

COUPLING	SYMBOL	DESCRIPTION
Pin or Revolute		Degrees of Freedom: 1 Rotation, 0 Translation
U-Joint		Degrees of Freedom: 2 Rotation, 0 Translation
Gimball		Degrees of Freedom: 3 Rotation, 0 Translation on a fixed defined axis..
Cylindrical		Degrees of Freedom: 1 Rotation, 1 Translation
Slider		Degrees of Freedom: 0 Rotation, 1 Translation
Planar		Degrees of Freedom: 1 Rotation, 2 Translation
Ball		Degrees of Freedom: 3 Rotation, 0 Translation on a unreferenced / undefined axis.
Free		Degrees of Freedom: 3 Rotation, 3 Translation
6 DOF		Degrees of Freedom: 3 Rotation, 3 Translation
Bearing		Degrees of Freedom: 3 Rotation, 1 Translation
Weld		Degrees of Freedom: 0
Slot		2D Planar open path movement (Curve path/Follower point)
Cam		2D closed path movement (Driver Cam/Follower Cam)
Ground Point		Fixed point in WCS

2) Mechanica Motion Toolbox – Loading Library

TYPE OF LOAD	SYMBOL	DESCRIPTION
Fixed Force		Force in a fix direction according to a defined axis and point.
Follower Force		Force assigned to a point on a moving component (Linearly & Angularity)
Fixed Torque		Moment around a defined axis
Follower Torque		Moment around a point on a moving component(Linearly & Angularity)
Joint Axis		Force between to components along the defined axis or coupling Friction
Point to Point		Force between two components.
Driver		Define a Velocity, Displacement or Accelerations at axis or joint
Bushing		Loads along the axis of a 6 DOF joint that connects two parts
Flexible Beam		Force or a Torque along a axis of a 6 DOF joint that connects two parts.
Gravity		Gravity along a any defined axis in the WCS.
Custom		Combination to user requirement

H. AMMUNITION DATA

PMP a Div of DENEL is one of our main ammunition manufacturers. PMP specialises in the development and manufacturing of small to medium calibre ammunition for the local and the export market. Research and development in this field assisted the author to obtain data related to foreign ammunition. Besides accessibility to Data Sheets, Ammunition Development Specifications and Reports at PMP, overseas manufacturer's of foreign ammunition were also approached for data that could assist in the development of the GAMA.

Listed below is a summary of publications used:-

1. Data Sheet: 12.7x99 mm, Ball; Tracer; IT; API; APIHC Ammunition (TP0682-6/1), PMP [078]

2. Data Sheet: 20x82 mm, TP; TPT; HEI; HEIT; SAPHEI Ammunition, 20x82/1, PMP [079]

3. Ammunition Interface Control Document 20x82 mm, 03371-01-0002, PMP [080]

4. Data Sheet: 14.5x114 mm Ammunition and Chamber, Triebe-, Waffenwerkzeuge G-[7] [081]

5. Data Sheet: 20x102 mm Vulcan TP; TPT; AP; API; HEI; HEIT-SD Fabricaciones Extremeñas S.A. [082]

6. Data Sheet: Municion Para Cañoness A.A (Ammunition for A.A. Cannons) 20/70 (20x110 mm) HEI; HEIT Fabricaciones Extremeñas S.A. [083]

7. Specification 20mm Hispano Suiza Cartridge Type 804 for Aircraft, Anti Aircraft and Infantry Guns, Unknown [084]

8. Specification Ammunition and Chamber Data: Standardisation Agreement 20 mm Ammunition for Airborne Weapons US M50 Series (20x102 mm) STANAG 3585 Ed 2, NATO, July 1973 [085]

9. Army Ammunition Data Sheets - Small Calibre Ammunition FSC 1305, TM 43-0001-27, Headquarters of the Army Washington, June 1981[086]

10. Ammunisie Spesifikasie vir Hoëdruk Rondtes vir 20mm GA1 Geskut, 376/09001/0082/A/03, LIW, Junie 1984 [087]

---

[7] Unknown / Not visible on paper copy

11. Data Sheet: 12.7x99 mm Ammunition, Small Caliber Ammunition, Olin Corp, 1986 [088]

12. Product and acceptance specification for Round 20mm PRAC M2A1 Type 151, 03-1305-3502-0-10401 Issue 4, PMP, 22 September 1987 [089]

13. Product and acceptance specification for Round 20mm HEI M1A3 Type 151, 03-1305-3503-0-10401 Issue 6, PMP, 22 September 1987 [090]

14. Product and acceptance specification for Round 20mm SAPHEI M1A2 Type 151, 03-1305-3504-0-10401 Issue 5, 14 September 1987 [091]

15. Small Arms Today - Latest report on the world's Weapon and Ammunition, 2nd Edition, Edward C Ezell, Stackpole Books, 1988 [092]

16. Product and acceptance specification for Round 20mm PRAC-T M1A1 Type 151, 03-1305-3693-0-10401 Issue 4, PMP, 11 February 1988 [093]

17. Product and acceptance specification for Round 20mm HEI-T M1A3 Type 151, 03-1305-3739-0-10401 Issue 7, 11 February 1988 [094]

18. Development Specification for 20x110 mm HS 804 Type TP; TP-T; HEI; HEIT, 04649-010001-115001 Issue 1, PMP, July 1991[095]

19. Data Sheet: 20x102 mm TP; TPT; SAPHEI Improved 20mm Ammunition, Olin Corp 1992 [096]

20. Report: 14.5 mm Wapentoetse, SVPB/001/92, PMP, 23 January 1992 [097]

21. Cannon 20 to 40 mm Calibre – Design Safety Principles and Guidelines for the Testing and Assessment of safety and suitability for service pillar proceeding, Ordnance Board Proceeding P105 & P107, Ordnance Board London, July 1992 and September 1992 [098]

22. Data Sheet Facsimile : 20x102 mm, Cartridge Cal 20mm HEI, M56A3, De Kruithoorn N.V. S-Hertogenbosch Holland, 7 September 1995 [099]

23. Data Sheet: 20x102 mm TP Ammunition, Companhia Brazilleira de Cartuchos, 30 May 1996 [100]

24. Condensed Specification for 12.7x99 BALL and Tracer Boxer, 03-13X2301-23008, PMP, June 1996 [101]

25. Facsimile - Specification: 20x102 mm TP Ammunition, SS-CBC 082.309.09A, Companhia Brazilleira de Cartuchos, 18 February 1997 [102]

26. Ammunition Specification for the GAMA Weapon System 12.7x99 High Pressure Rounds, 747/00002/0200, Author (Vektor), 1 October 1997 [103]

27. Facsimile Data Confirmation: 12.7x99 mm & 20x82 mm Ammunition Performance Data 27 October 1997 [104]

28. Facsimile - Drawings: 12.7x99 mm Ammunition, PMP, 13 February 1998 [105]

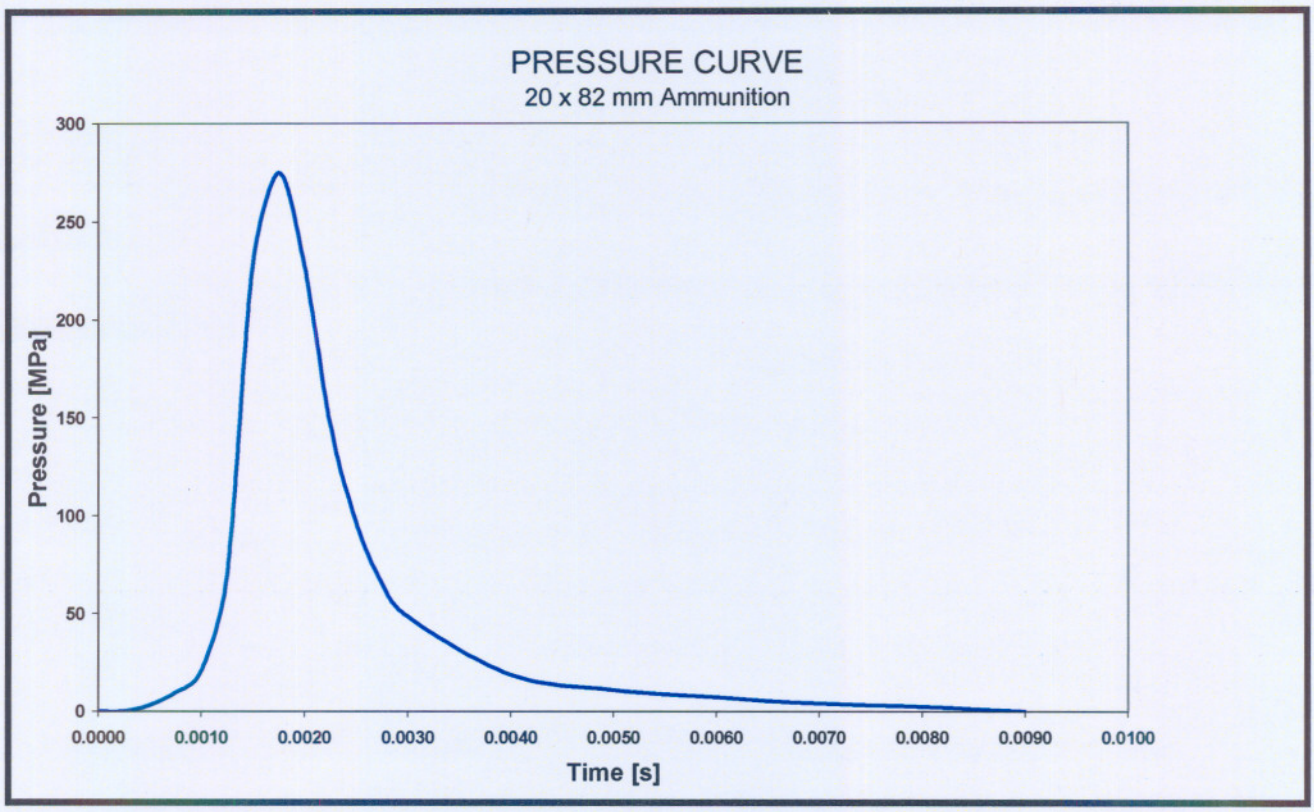
29. Facsimile: 20x102 mm Ammunition, Raufoss Technology AS, 25 June 1998 [106] ,

30. Jane's Ammunition Handbook, Ninth Edition 2000-2001, Terry J. Gander and Charls Q. Custhaw, Janes Information Group Inc. [107]

31. Munitions pour cannon de 20 MG 151, MANURHIN [108]

1) 20x82 mm MG-151 Ammunition Interface

Measured Pressure Time curve of a typical 20x82 mm Round





Ammunition types used during GAMA development: PRAC , HEI be applicable

Piezo pressures through cartridge case

$P_{(Average)}$	=	275 MPa at 21°± 2° Celsius
$P_{(Average)} + 3\sigma$	=	310 MPa at 21°± 2° Celsius
$P_{(Temp\ max/min)}$	=	296 MPa at 60° Celsius
$V_{(Muzzle\ Average)}$	=	720 m/s
Mass: Round	=	205 g
Projectile	=	110 g
$P_{(High\ Pressure\ )}$	=	330 - 350 MPa

2) 12.7x99 mm Ammunition Interface



Ammunition types used during GAMA development: Ball, Tracer
Copper crusher pressures in front of cartridge case.

$P_{(Average)}$ = 340 MPa at 21º± 2º Celsius
$P_{(Average)} + 3\sigma$ = 380 MPa at 21º± 2º Celsius
$P_{(Temp\ max/min)}$ = 362 MPa at 52º Celsius
$V_{(Muzzle\ Average)}$ = 865 m/s ± 12 m/s
Mass = 146 g
$P_{(High\ Pressure)\ min}$ = 472 MPa (Piezo) / 429 MPa (Copper crusher) at 21º
$P_{(High\ Pressure)\ max}$ = 493 MPa (Piezo) / 448 Mpa (Copper crusher) at 21º
$[P_{(High\ Pressure\ )MIN} > (P_{(Temp\ max/min)} + 3\sigma)]$ [096]
$[P_{(High\ Pressure\ )MAX} > (P_{(Temp\ max/min)} + 4.75\sigma)]$
Proof Pressures =550-570 MPa International 12.7x99 mm

3) 14.5x114 mm Ammunition Interface



Ammunition types to be used during GAMA development: Ball

$P_{(Average)}$ = 409 MPa at 21º± 2º Celsius
$V_{(Muzzle\ Average)}$ = 1030 m/s
Mass = 190 g
$P_{(High\ Pressure\ )}$ = 540 MPa

4) 20x102 mm Ammunition Interface



Ammunition types to be used during GAMA development: TP

$P_{(Average)}$ = 417 MPa at 21º ± 2º Celcius
$V_{(Muzzle\ Average)}$ = 1030 m/s
Mass = 257 g
$P_{(High\ Pressure\ )}$ = 431 - 500 MPa Test Ammunition

5) 20x110 mm Ammunition Interface



Ammunition types to be used during GAMA development: Ball and HEI

$P_{(Average)}$	= 304 MPa at 15º ± 2º Celsius
$V_{(Muzzle\ Average)}$	= 850 m/s ± 15 m/s
Mass	= 260 g
$P_{(High\ Pressure\ )}$	= 363 MPa

I. TYPICAL INTERNAL BALLISTIC DATA

1) Barrel and Ammunition 20x82 mm Input File

File: IB20x82mm.INP

***20x82 GUN & AMMUNITION**

0.100	: Projectile mass (kg)
0.039	: Charge mass (kg)
0.020	: Bore diameter (m)
1.027	: Shot travel (m)
5.9874E-6	: Projectile Izz (kg m^2)
0.16	: Coefficient of friction

***PRESSURE**

0.00E+00	0.00E+06
5.00E-04	3.13E+06
7.50E-04	9.38E+06
1.00E-03	2.03E+07
1.25E-03	6.88E+07
1.50E-03	2.28E+08
1.75E-03	2.75E+08
2.00E-03	2.28E+08
2.25E-03	1.47E+08
2.50E-03	9.69E+07
2.75E-03	6.56E+07
3.00E-03	4.84E+07
4.00E-03	1.88E+07
5.00E-03	1.09E+07
6.00E-03	7.19E+06
7.00E-03	4.06E+06
8.00E-03	2.50E+06
9.00E-03	0.00E+06

***ALPHA**

0.0E-3	6.5
1027.0E-3	6.5

2) Barrel and Ammunition 20x82 mm Output File

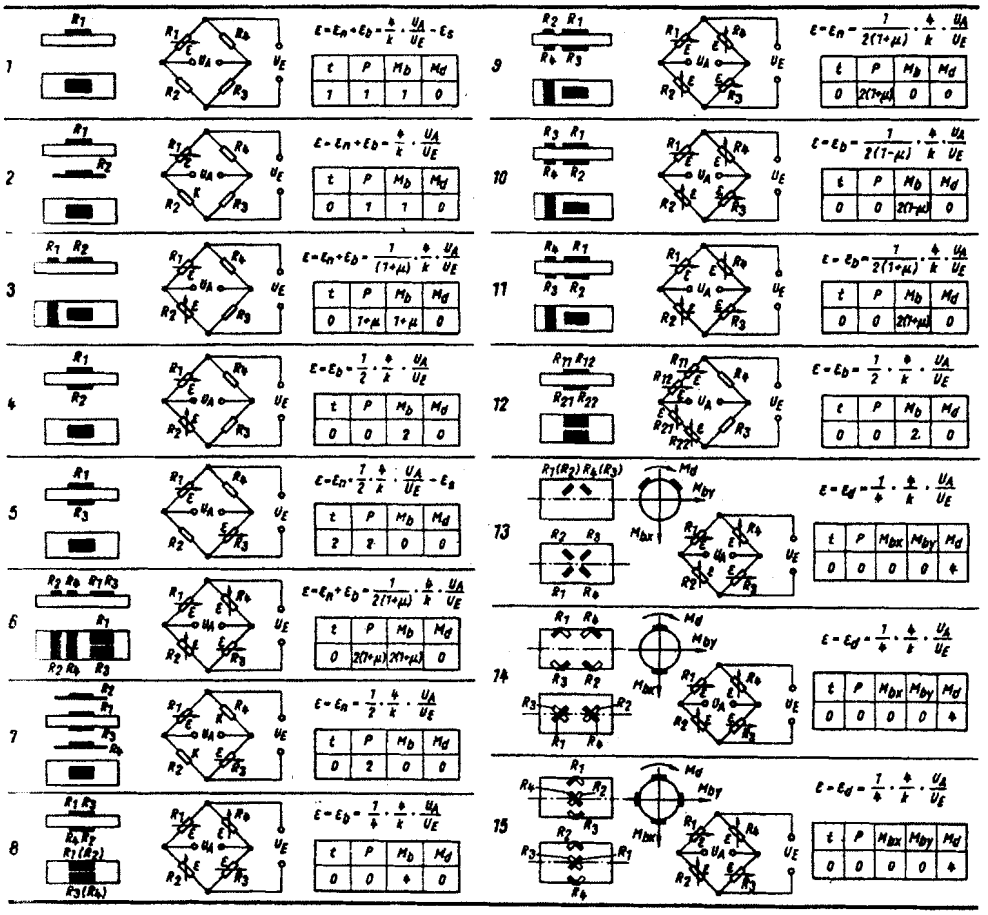
File: IB20x82mm.OUT

Time [ms]	Pc [Pa]	Pb [Pa]	ResF [N]	Force [N]	Acc [m/s2]	Vel [m/s]	Disp [m]	Alfa ø	Spin [Refs/min]
0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.000E-04	3.130E+06	2.869E+06	4.906E+02	8.523E+02	7.748E+03	3.874E+00	1.937E-03	6.500E+00	4.215E+02
7.500E-04	9.380E+06	8.598E+06	1.470E+03	2.554E+03	2.322E+04	9.679E+00	4.357E-03	6.500E+00	1.053E+03
1.000E-03	2.030E+07	1.861E+07	3.182E+03	5.528E+03	5.025E+04	2.224E+01	9.917E-03	6.500E+00	2.420E+03
1.250E-03	6.880E+07	6.307E+07	1.078E+04	1.873E+04	1.703E+05	6.482E+01	2.612E-02	6.500E+00	7.053E+03
1.500E-03	2.280E+08	2.090E+08	3.574E+04	6.209E+04	5.644E+05	2.059E+02	7.760E-02	6.500E+00	2.240E+04
1.750E-03	2.750E+08	2.521E+08	4.311E+04	7.488E+04	6.808E+05	3.761E+02	1.716E-01	6.500E+00	4.092E+04
2.000E-03	2.280E+08	2.090E+08	3.574E+04	6.209E+04	5.644E+05	5.172E+02	3.009E-01	6.500E+00	5.627E+04
2.250E-03	1.470E+08	1.347E+08	2.304E+04	4.003E+04	3.639E+05	6.082E+02	4.530E-01	6.500E+00	6.617E+04
2.500E-03	9.690E+07	8.882E+07	1.519E+04	2.639E+04	2.399E+05	6.682E+02	6.200E-01	6.500E+00	7.270E+04
2.750E-03	6.560E+07	6.013E+07	1.028E+04	1.786E+04	1.624E+05	7.088E+02	7.972E-01	6.500E+00	7.711E+04
3.000E-03	4.840E+07	4.437E+07	7.587E+03	1.318E+04	1.198E+05	7.387E+02	9.819E-01	6.500E+00	8.037E+04
4.000E-03	1.880E+07	1.723E+07	2.947E+03	5.119E+03	4.654E+04	7.414E+02	1.027E+00	6.500E+00	1.559E+05

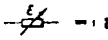
J. STRAIN GAUGE BRIDGE CIRCUIT REFERENCE SHEET

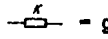
The following is an extraction from the HBM Strain Gauge booklet: Applying the Wheatstone Bridge Circuit by K Hoffmann.

HBM 16



Note: A cylindrical shaft is assumed for torque measurement, examples 13, 14, 15. For reasons of symmetry bending in X and Y direction is allowed. For the bar with square or rectangular cross section the same conditions are valid. Explanation of symbols: t = temperature, P = normal force, M_b = bending moment, M_{bx}, M_{by} = as M_b but for X and Y directions, M_d = torque. These influence result in strains ϵ_t, ϵ_n, ϵ_b, ϵ_{bx}, ϵ_{by}, ϵ_d respectively. ϵ is the effective strain at the point of measurement Z_o for P and M_b in normal (axial) direction, for M_d under $\varphi = +45°$.

 = active strain gauge,

 = gauge for temperature compensation

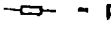
 = passive gauge or resistor

Table compiled by Mr. J. Bornhardt, first published in ELEKTRONIK 16 (1967) No. 9.

K. CORRESPONDENCE RELATED TO THE GAMA PROJECT

The following are either an extraction from the author's electronic mail server or copies of documentation that are relevant to the GAMA project.

1) Demonstration: United Kingdom - Harley Valley, South Wales

From: **Dirk Taljaard**
Sent: 05 July 1997 10:32 AM
To: 'GES/SAT'
Cc: Leon Pienaar; Andre van Heerden
Subject: RE: GAMA CANNON DEMONSTRATION IN JULY

Dear Rui, thank you for your comments and fax send to Brain Tucker and Leon Pienaar (by Mr.Cardoso.) We will act on your recommendations and reply to you.
Since we have been unable until now to get confirmation from yourself and BAF on your attending the demonstration in 2 weeks, we have decided to send the GAMA Cannon to the UK for a demonstration to the MOD on there request. It will be back by the 25 of July meaning we can give the demo by 30 July.
Final details to be send later.

Regards, Dirk

---

2) Demonstration: Brazilians-Roodewal Bombing Range Pietersburg

From: **GES/SAT[SMTP:gessat@embraer.com.br]**
Sent: 03 July 1997 12:58
To: Dirk Taljaard
Subject: GAMA CANNON DEMONSTRATION IN JULY

Dear Mr. Dirk

We agree with your test program proposal (Appendix A of your last Fax) for the new demonstration, with the following recomendations below:

1- To control the systematic deviation, before and after firing;

2- To measure the dispersion cones (80% and 100%).

Please confirm the schedule for this test.

Best Regards

Rui Dias

---

3) Generation of an International Press Release

From: Basch , Sam [SamB@denel.co.za]
Sent: 13 November 1998 10:14 AM

To: Andre van Heerden
Cc: Karries Karemaker
Subject: RE: media release

Andre

Dankie hiervoor. Ek het reeds die veranderinge op my afskrif gemaak - inderdaad die terme uitgeskryf sodat leke-joernaliste dit ook sal verstaan - en by die skou druk ek die vrystelling na behoefte uit.
Trouens, ek het 'n vouer waarin ek die goed uitgee, waarin ek ook die foto's insit.

Ek kan jou byna van publisiteit waarborg, want daar is joernaliste van die tegniese tydskrifte wat hierin sal belangstel. Dit sal ook gepos word aan ander wat nie by DEXSA sal wees nie.

By die skou sal ek mense na jou toe bring om verder hieroor te gesels.

Jou hulp word hoog op prys gestel.

SAM

From: Andre van Heerden[SMTP:AndreV@liw.denel.co.za]
Sent: 13 November, 1998 09:54
To: 'samb@ denel.co.za'
Cc: Karries Karemaker; Frans Germishuizen; Dirk Taljaard; Eric Van Eeden
Subject: FW: media release

<<File: Gama1.doc>>

-----Original Message-----
From: Basch , Sam [SMTP:SamB@denel.co.za]
Sent: 12 November 1998 12:00
To: Andre van Heerden
Cc: Karries Karemaker
Subject: media release

Andre
Enclosed is the GAMA media release as I've adapted it. Please check for factual accuracy, although I've not changed any technical info.
It ABSOLUTELY VITAL that I get a batch of the photograph showing the different barrels. We normally have a supply of around 50 copies on hand to give to the journalists. Each photograph must have a caption on the back (self-adhesive labels) just to indicate what it is, and when the picture was released (1998). Remember, journalists might separate the pictures from the media release, with the result that they no longer remember what is depicted in the photograph.
Can you order me the supply of photographs?
Finally, I believe Karries or Brian Tucker should give approval for the release.
Kind regards

SAM J BASCH

---

4) Negotiations: Ammunition Manufacturers Participation in GAMA

a) Primex Technologies Inc.

From: **Max Waterman [SMTP:MWaterman@email.msn.com]**
Sent: 19 November 1998 05:46
To: Karries Karemaker
Subject: 20 x 102 mm Rounds for GAMA

Dear Adrian,

It was a pleasure to meet with you at DEXSA 98. I know that you will be extremely busy following the show, however I would be grateful if, by return of E-mail, you would forward to me a formal request for quotation for the 20 x 102 mm High Pressure rounds you requested, as well as your request for a box of free issue HE ammunition for the GAMA.

I believe that on the basis you would be willing to work with us in the future, allowing us to become your **exclusive 20 x 102 supplier**, we may be in a position to help out.

Please forward this at your earliest opportunity.

Many thanks and best regards,

Max Waterman
Director International Marketing
Primex Technologies Inc

From: Max Waterman[SMTP:MWaterman@email.msn.com]
Reply To: Max Waterman
Sent: 27 May 1999 12:35
To: Eric Van Eeden
Cc: Gleason, Tom; Fahrney, Gary - Marion
Subject: Re: Primex 20x102 ammunition for GAMA

Eric,

Many thanks for the request. This has been passed to the Marion plant to raise a quotation for you. Our minimum order quantities are generally in the 25 - 50,000 round range for these natures of ammunition, however I am hopeful of being able to pull something together for you from inventory.

I was discussing with Andre the possibility of a longer term relationship with Vektor for ammunition supply - would be grateful at some later stage for the opportunity to go through this with you.

Will revert as soon as information received.

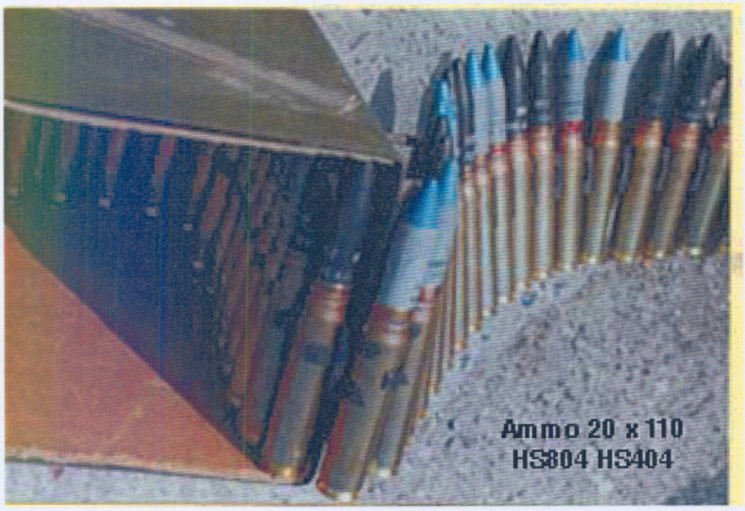
Many thanks and best regards

MW

---

b) Eurodef Ltd.

From: ordtec[SMTP:ordtec@ordtec.com]
Sent: 21 May 1999 01:50
To: Eric Van Eeden
Subject: E90521-LW1 ref. ammo 20x110 20x102



From: EURODEF LTD
22 LEOF. DIMOKRATIAS
NEO PSYCHIKO 15451 - GREECE

e-mail: eurodef@ordtec.com

web: www.ordtec.com

Fax: 30 - 1 - 672-2794 **Tel:** 674-7534

Subject: Enquiry for ammo 20 mm x 110 and 20 mm x 102

SUBJECT 2

Coming to the ammo enquiry now: there exist million of rounds of 20 mm x 110 in all types including TP target practice. Other types include HE, HEI, AP, API, APIT, Incendiary, etc. These rounds were manufactured in the 1970s but are fully functionable as trials prior to sale to Asian and South American Customers last year demonstrated.

This ammo was declared as surplus because all three armed forces use the following calibres: 30 x 173, 20 x 139, 23 x 152 and the 20 x 110 weapons (in AAA roles) are obsolete.

The price is $3.15 USD per round for typical orders of a good few thousands (say 15000 to 20000 rounds). For larger quantities we can negotiate with the MoD a much better price.

Regarding minimum order quantity: we have not really addressed this issue so far. All sales were minimum one container load with empty space, as its maximum capacity of 30000 rounds was not ordered.

Pressumably we will have to examine the MOQ issue on the following basis: a] the transportation cost b] whether the MoD will consider being involved in a small order c] your budget and actual operational requirements.

Regarding transport, we can safely state that since it is IMCO class, the cost for one container, half full or full, would cost $9500 USD or more from Piraeus to Durban. Air transport for smaller quantities,

say 1000 rounds, would also be possible but only on cargo aircraft, e.g LUFTHANSA or SWISSAIR via Europe. In this case the red tape and need for various permits plus the high air transport cost itself, would almost double the value of each round by the time it would
get to Jan Smuts.

Regardless of the cost, which is an issue to be considered taking into account your feedback on [b] and [c] above, there will be a requirement for an export license. This should present no problem at all for RSA and does not take very long.

Since RSA is a non NATO country, in addition to MoD and Foreign Affairs Ministry there is a need for Cabinet final approval. The latter
is only a formality once the other two have given the green light.
The time typically taken is 7 weeks and in extreme cases 9-10 weeks.

This time counts from receipt of three (3) original EUCs (End User Certificates) which can be on MoD, ARMSCOR or S.A.D.F letterhead, stating the intented use of the ammo and signature of official verified by Hellenic Embassy in Pretoria. (standard practice).

SUBJECT 3
Coming to 20 x 102 mm VULCAN M61 and M39A2 cannons ammo: this we can supply also, but there is no surplus stock.
Our Air Force alone has some 550 guns of the two above types and a smaller quantity with Navy Phalanx and Army mobile units.
We can supply TP, TP-T and HEI, HEI-T rounds the cost of which, linked new production is $11.95 for practice and combat rounds start from $13.95 to $16.55 depending on the type.
The designation PGU is not immediately identifiable; could it be perhaps multi-purpose or telescopic ? please advise.

I hope the enclosed information is of some use to you so as to be able to make calculations and move the project to its next phase.

Please do not hesitate to contact me if you need any additional data or to discuss other details. My cellular number is 30 - 932 - 46.29.18

I look forward to hear from you soon.

Kind Regards

Yiannis Kavaratzis

---

5) Demonstration: SANDF – GAMA Integrated with OWS Platform.

From: Dirk Taljaard
Sent: 07 July 1999 03:05 PM
To: Andre van Heerden
Subject: AMS

Bevestig AMS vir week van 26e, en hou die 29e oop vir 'n klein demo aan SANW van die OWS stelsel.
Dirk

---

6) Demonstration: Tanzania - GAMA Integrated with OWS Platform.

From: Dirk Taljaard
Sent: 11 August 1999 05:19 PM
To: Andre van Heerden; Willie Morrison; Herman Louw
Cc: Frans Germishuizen; David Barnes; Karries Karemaker
Subject: DEMO TANZANIE 20/8/99

Menere,
Ons beplan 'n demo aan Tanzanie (Krygkor - Gert Hattingh) op 20 Augustus 99 te Paardefontein om 13h00. (Op OWS montasie op bote.)
Wapens: Gama 82/12,7/14.5/110 op driepoot.
AGL op driepoot.
Bevestig asb julle instemming.

Herman, kan jy asb die baan reël so gou as moontlik - kostes, baanoff. dokumente ens.

Dankie, Dirk.

---

7) Show: EUROSATORY

From: Karries Karemaker
Sent: 16 February 2000 03:46 PM
To: Dirk Taljaard; Ken Becker
Cc: Frans Germishuizen; Andre van Heerden; Eric Van Eeden
Subject: RE: GAMA EUROSATORY

Dirk
As dit die enigste GAMA is dan moet ons asb so reel dat dit gaan.

Dankie
Karries

-----Original Message-----
From: Dirk Taljaard
Sent: 16 February 2000 10:08
To: Ken Becker
Cc: Karries Karemaker; Frans Germishuizen; Andre van Heerden; Eric Van Eeden
Subject: GAMA EUROSATORY

Ken,
Die enigste GAMA wat beskikbaar is, is die een wat in die uitstalarea is. As dit reg is met Karries kan ons hom stuur.
Ek stel voor dat hy vir kortste moontlike tyd gaan, nie maande voor die tyd nie, en so gou moontlik terug kom.

Dirk

---

8) Request GAMA for Black Hawk UH-60 Helicopter

05/31/00 17:45 ☎57 1 2880938 MAGSIND LTDA. 001

MAGSIND LTDA
MUNDIAL DE AGENCIAS Y SERVICIOS INDUSTRIALES
CARRERA 7ª No. 37 - 25 PISO 2º
SANTA FE DE BOGOTA D. C.- COLOMBIA

FAX

CONMUTADOR: 338 22 66
FAX NUMERO: 288 09 38
magsind@impsat.net.co

FAX DESTINO / DESTINATION FAX: (00927) 126 202 407	FECHA / DATE: MAY 31, 2000
A / TO: LEON PIENAAR	CIA. / COMPANY: VEKTOR
DE / FROM: GERARDO PARDO SOFÁN	FAX No. / NUMBER FAX: 650-00
ESTE FAX CONTIENE / THIS FAX CONSIST OF: 1 PAGINA(S)/PAGE(S)	PÁGINA No. / PAGE No.: 1/1
SI USTED NO RECIBE TODAS LAS PAGINAS DE ESTE FAX, POR FAVOR INFORMENOS INMEDIATAMENTE KINDLY ADVISE US INMEDIATELLY IF THIS DOCUMENT WAS NOT RECEIVED CORRECTLY	

URGENT

REF: 20mm CANNONS TO FIRED AMMUNITION NATO 20 X 102mm.

Dear Leon:

According to your telephone conversation with Julio Zalamea, please send us the 20mm cannon quotation including in the price:

- .50mm barrel conversion kit.
- A barrel for ammunition 20 x 102mm

On the other hand, the 20mm cannons will be installed on the POD of the Black Hawk UH-60 helicopters. Please be advised that it is very important to delivery a POD for the demonstration, due to the fact that such acquisition would not be open to other competitors just for us (MAGSIND LTDA), and they will only decide the purchase of the material depending of the demonstration results.

Please keep in mind the following:

- The Colombian Black Hawks used French perchas to catch the POD.
- The CAF does not want an ammunition box (which it is attached to the POD), they want an exter or box, that could store a lot more than 250 rounds.

Finally, I would appreciate your prompt quotation at the latest by tomorrow 9:00 a.m. Colombian, in order to present the offer to CAF. This business seems very good.

My Best Regards,

P/P GERARDO PARDO SOFÁN
General Manager

01 JUN 00 (THU) 00:45 COMMUNICATION N: 51 PAGE: 1

9) Request GAMA for Augusta A109 Helicopter

CONFIDENTIAL

Telephone: (012) 428-2328
Facsimile: (012) 347-0101
Enquiries: Lt Col M.H.Christie

JAPO/C/10.3/3990/6.6

Department of Defence
Departmental Acquisition and
Procurement Division
Directorate Air Force Acquisition
Private Bag X910
Pretoria
0001
14 February 2002

Programme Manager Weapon Systems
Mr G.F.S. Hattingh

ARMAMENT REQUIREMENT FOR PROJECT FLANGE: SAAF AGUSTA A109

1. Project FLANGE is in the process of investigating the Armament requirement for the A109 with the OPO and HSG.

2. The Agusta A109 URS, version 5, page 16 and par 25.1.9 refers to the Gamma GA1 multi calibre cannon and automatic grenade launcher as a strap-on cannon. This requirement is still outstanding and the Systems Group must decide if this requirement still exists. It has been decided that the canon/machine gun will be a door mount. The calibre size needs to be resolved. The first SAAF A109 airframe is already on the assembly line and the possibility of changing the airframe structure will not be cost-effective or feasible.

3. Any additional information regarding the details and the status of the Armament for the A109 will be appreciated. Information can be forwarded to the local Project Office.

(M.H. CHRISTIE)
PROJECT FLANGE TECHNICAL OFFICER RSA: LT COL

10) Request GAMA in a Gunpod for Brazilian's Aircraft

From: Philippe T. Braganca [mailto:ptbamb@iis.com.br]
Sent: 06 May 2004 09:23 PM
To: Leon Pienaar
Subject: RE: Embraer 20 mm cannon & pod

Dear Leon,
Thank you for your message. Good answer. Will see what Rui's comments are. From what I can remember the 20x102 mm ammo was a Brazilian imposition, may be for the exported aircraft they can offer the other options.

Do you have an answer concerning the canopy severance cord? Embraer is very eager to import, also they asked me if there are seat ejection charges made in South Africa. would you know who makes them?

Sorry to hear that you have to travel so much. I tried to call you at home yesterday, but a lady answered and said you no longer lived there (I dialed 997-1376). What is your new number? Is your office number still 620-9111? Please confirm.

Best regards,
Philippe

********** **REPLY SEPARATOR** **********

On 5/6/2004 at 1:38 PM Leon Pienaar wrote:
Hello Philippe,

I have been out of country for some time. Before I left I made contact with Graham and asked him to contact you if only just to send my regards. I will be out of office next week again.
You will remember that the weapon namely the GAMA could fire different calibres namely 12.7mm, 14.5mm, 20 x 82mm, 20 x 110mm and 20 x 102mm. Regarding Rui's message all I can say is that Vektor has qualified the weapon but not for the 20mm x 102mm ammunition (the calibre used by Brazil). The system can definitely handle the 20 x 102mm ammunition but Vektor still had to fire at least a few hundred rounds more before the weapon could be qualified with the 20x 102 ammunition. Vektor has not done this yet.
I hope this will clarify the situation. I am sure it will not cost very much to finalise and qualify the weapon. One of the engineers that used to work on the project is still involved with the weapon - **he is doing his doctorate** on the weapon and therefore I can assure you that the weapon has not been moth-balled yet.
Regards,
Leon

-----Original Message-----

From: **Philippe T. Braganca [mailto:ptbamb@iis.com.br]**
Sent: 21 April 2004 09:52 PM
To: Leon Pienaar
Subject: Embraer 20 mm cannon & pod

Dear Leon,
Below is a translation of an email from Rui Dias, where he too insists on some news about the development of the 20 mm cannon by LIW, as I have requested you in my last email.
Could you please give me a return on this?
Best regards,

Philippe

********** **BEGIN FORWARDED MESSAGE** **********

On 4/21/2004 at 9:18 AM rdias@embraer.com.br wrote:

D. Philippe,

Pod do Canhão de 20 mm. Conversei com o Henrique. Não existe nada de
20 mm cannon pod: I spoke with Henrique. There is nothing concrete on this
concreto nesta eventual aquisição. De fato ele andou questionando alguma
potential acquisition. In fact, he asked some questions concerning this subject
coisa com relação a este assunto quando esteve na África do Sul. Mas sem
when he was in South Africa, but without having anything in sight.....
nada em vista...
Ainda com relação ao pod do canhão da LIW, eu gostaria de saber se houve
Still with regard to the pod of LIW's cannon, I would like to know if there was
alguma evolução. Paramos no ponto em que ela estava fazendo um "upgrade"
any development. We stopped at the point where LIW was doing an "upgrade"
no canhão, para emprego da munição brasileira. Houve algum progresso?
on the cannon, for the use of Brazilian ammo. Has there been any progress?
Recomendações ao Sr. Leon Piennar (grande pessoa).
My regards to Mr. Leon Pienaar (a great guy).

Atenciosamente,
Sincerely,
Rui

L. DATA BASES USED DURING THE DEVELOPMENT OF GAMA

1) Heading Extraction: Test Data Base Log File "GAM_DBT1.XLW"

Configuration Log Sheet

CONFIGURATION	DESCRIPTION	WEAPON	CRADLE	AMMUNITION

Test History Log

TEST INFORMATION								AMMUNITION					BURST LENGTH	SIGNAL	ROF	STOPPAGE		FRACAS	REMARKS
No:	Range	Time	Date	Series	Configuration	Type	File Name	Link #	Type	Load	Fire	Total	[s]	[ms]	[rpm]	Yes/No	Description	#	

Instrumentation Log

DATA REQUIREMENT							AMPLIFIER INFORMATION & CALIBRATION SETUP										DATA CAPTURING INFORMATION					TEST NO	
Grid / Node No	POSITION	SETUP	DESCRIPTION	NAME	SENSOR TYPE	SENSOR SERIAL No	CABLE TYPE & No's	AMPLIFIER TYPE & No	TRANSDUCER SENSITIVITY & RANGE			KISTLER ADDITIONAL SETTINGS			Ex V	Gain	Filter Hz	Calibration EU/V	Units	Offset	Duration [s]	Samp Freq [Hz]	From	To
												Time °C	Op. Mode	U. Mode									

Snag History Log

DATE	SERIES	FRACAS #	DESCRIPTION	ACTION

2) Heading Extraction: Simulation Log File "GA1&GAMA_DATA.xls"

Hardware Information and Static Measurements

DESCRIPTION OF MEASUREMENT	QAC?	MEASURED	CALCULATED

Component List and Information

COMPONENT DESCRIPTION	INFORMATION SOURCE	WEAPON CALIBRE COFIGURATION	MASS [kg]	C.G. IDENTIFICATION	Ixx [kg.m²]	Iyy [kg.m²]	Izz [kg.m²]	COMMENTS	Ixy [kg.m²]	Ixz [kg.m²]	Iyz [kg.m²]

Load List and Information

LOAD DESCRIPTION	*DRAWING No*	*DATA FILE NAME SPRING RATE [N/m]*	*FREE LENGTH [m]*	*SOLID LENGTH [m]*	*INSTALLED LENGTH [m]*	*PRE-TENSION [N]*	*COMMENTS*	*MEASURED FREE LENGTH [m]*	*MEASURED INSTALLED LENGTH [m]*	*CALCULATED SPRING PRE-TENSION [N]*	*MEASURED SPRING PRE-TENSION [N]*

Load and Connectivity Information

COUPLING	PART #1	PART#1 SUB.	PART #2	PART#2 SUB.	JOINT / LOAD TYPE	DESCRIPTION	CONDITIONS	*COMMENTS*

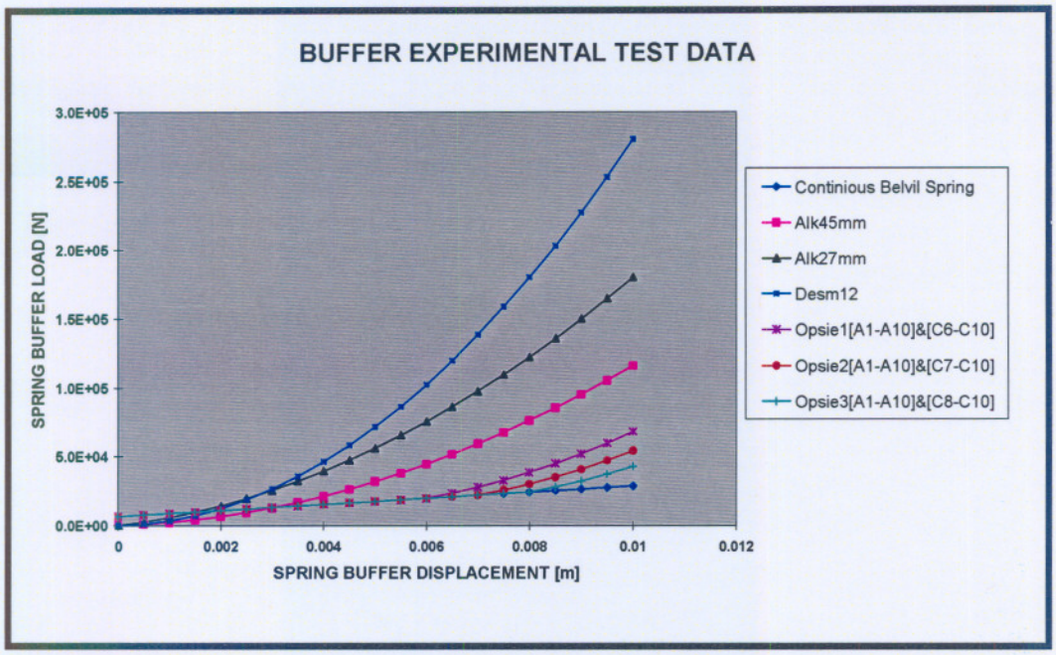
Layer Control

LAYER No.	LAYER DESCRIPTION	LAYER COLOR	COMPONENTS

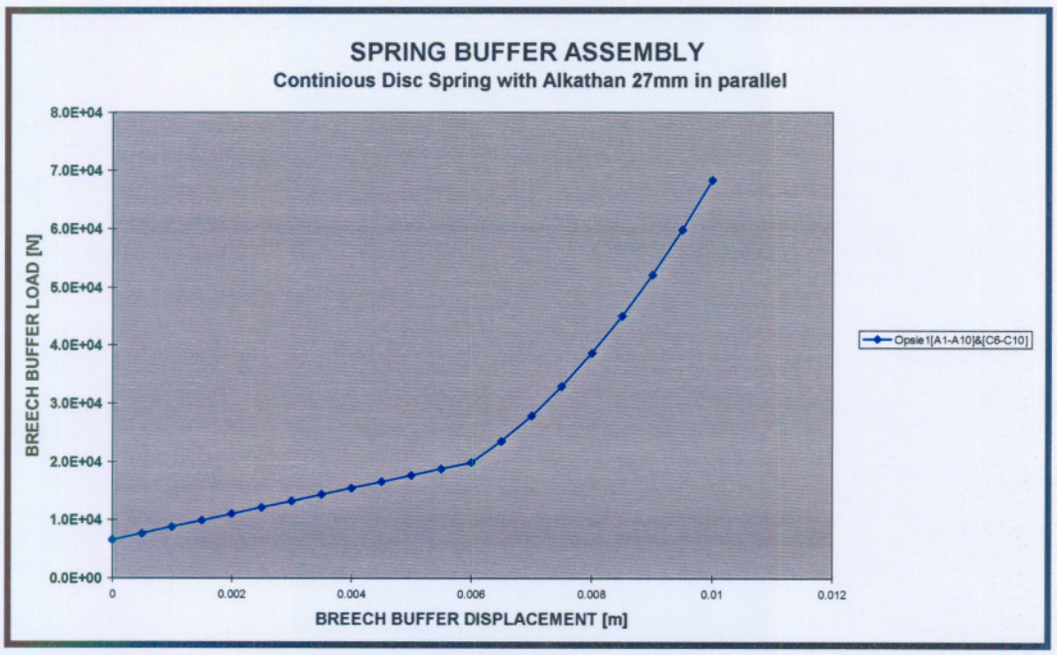
M. SIMULATION AND EXPERIMENTAL DATA

1) Breech Buffer Test Data

Various springs (Chapter 3.3; Figure 17) and their combinations were tested to match the breech buffer requirement dictated by simulation.



The combination of using the continuous disc spring in combination with Synthetic material (Alkathan) in series gave the correct response required to cater for any of the GAMA configuration.

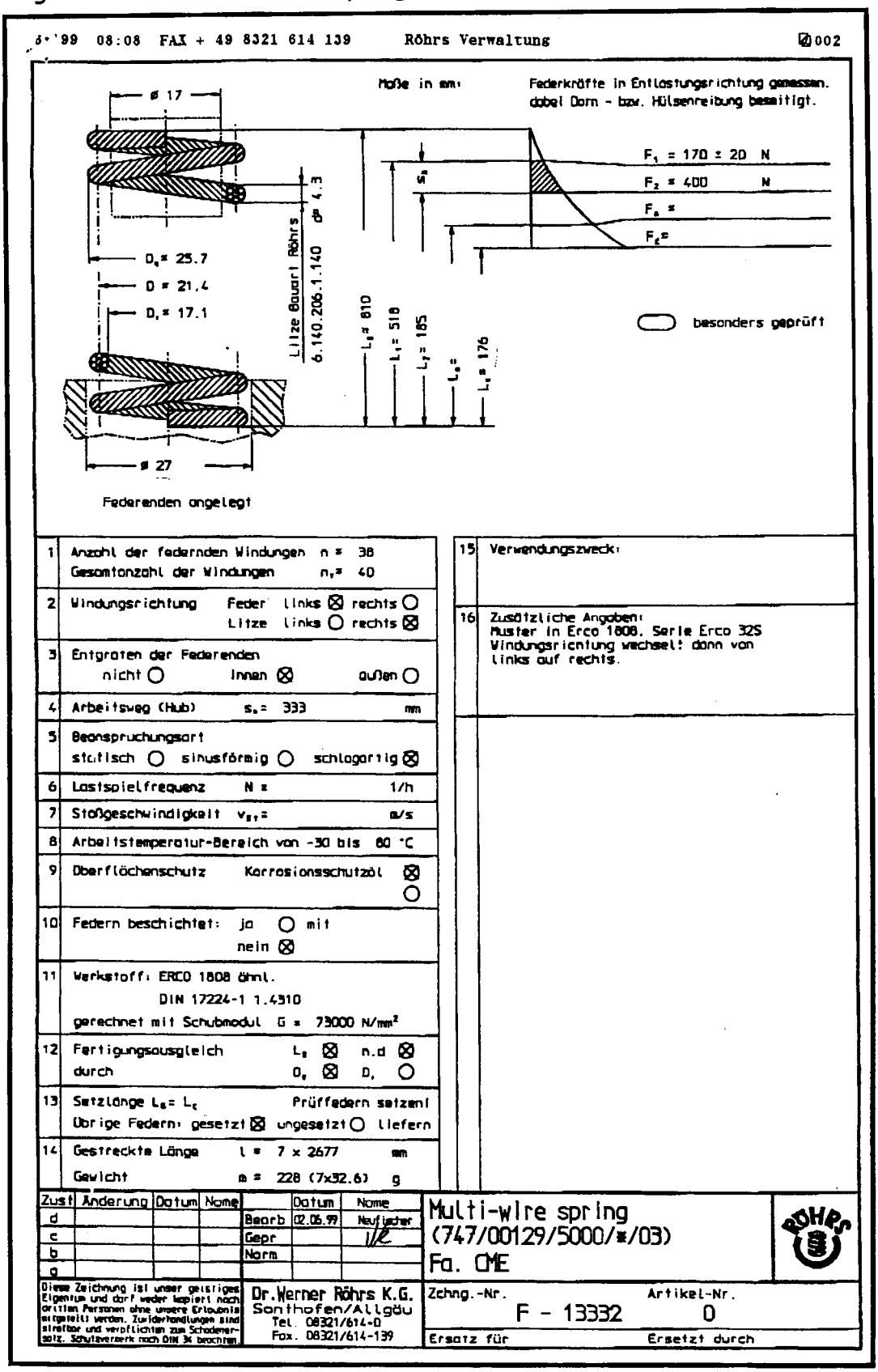


2) Recoil Spring Simulation Data

Simulation results requested a spring with the specification also pertained on drawing 747/00129/5000/∇/03

PARAMETER	DESIGN REQUEST
Assembled height (L1)	518 mm
Load at assembled height (F1)	170 N
Working height (L2)	185 mm
Load at working height (F2)	380 N
Outer restriction (Do)	27 mm
Inner restriction (Di)	17 mm
Working temperature	-10°C to +60°C
Block protection	180 mm
Period of compression cycle (N)	20 msec (0.020sec)
Minimum fatigue life	12 000 cycles

Röhrs manufactured the spring and the following certificate was issued together with the batch of springs.



6.'99 08:08 FAX + 49 8321 614 139 Röhrs Verwaltung 002

Maße in mm:

Federkräfte in Entlastungsrichtung gemessen, dabei Dorn - bzw. Hülsenreibung beseitigt.

ø 17

D_e = 25.7

D = 21.4

D_i = 17.1

ø 27

Litze Bauart Röhrs 6.140.206.1.140 ø 4.3

L_0 = 610

L_1 = 518

L_2 = 185

L_c =

L_s = 176

s_a

F_1 = 170 ± 20 N

F_2 = 400 N

F_a =

F_c =

besonders geprüft

Federenden angelegt

1	Anzahl der federnden Windungen n = 38 Gesamtanzahl der Windungen n_t = 40	
2	Windungsrichtung Feder links ☒ rechts ○ Litze links ○ rechts ☒	
3	Entgraten der Federenden nicht ○ innen ☒ außen ○	
4	Arbeitsweg (Hub) s_a = 333 mm	
5	Beanspruchungsart statisch ○ sinusförmig ○ schlagartig ☒	
6	Lastspielfrequenz N = 1/h	
7	Stoßgeschwindigkeit $v_{s,t}$ = m/s	
8	Arbeitstemperatur-Bereich von -30 bis 60 °C	
9	Oberflächenschutz Korrosionsschutzöl ☒ ○	
10	Federn beschichtet: ja ○ mit nein ☒	
11	Werkstoff: ERCO 1808 ähnl. DIN 17224-1 1.4310 gerechnet mit Schubmodul G = 73000 N/mm²	
12	Fertigungsausgleich L_0 ☒ n.d ☒ durch D_e ☒ D_i ○	
13	Setzlänge $L_s = L_c$ Prüffedern setzen! Übrige Federn: gesetzt ☒ ungesetzt ○ liefern	
14	Gestreckte Länge l = 7 x 2677 mm Gewicht m = 228 (7x32.6) g	
15	Verwendungszweck:	
16	Zusätzliche Angaben: Muster in Erco 1808, Serie Erco 32S Windungsrichtung wechselt: dann von links auf rechts.	

Zust	Änderung	Datum	Name
d			
c			
b			
a			

	Datum	Name
Bearb	02.06.99	Neufischer
Gepr		
Norm		

Multi-wire spring
(747/00129/5000/*/03)
Fa. CME

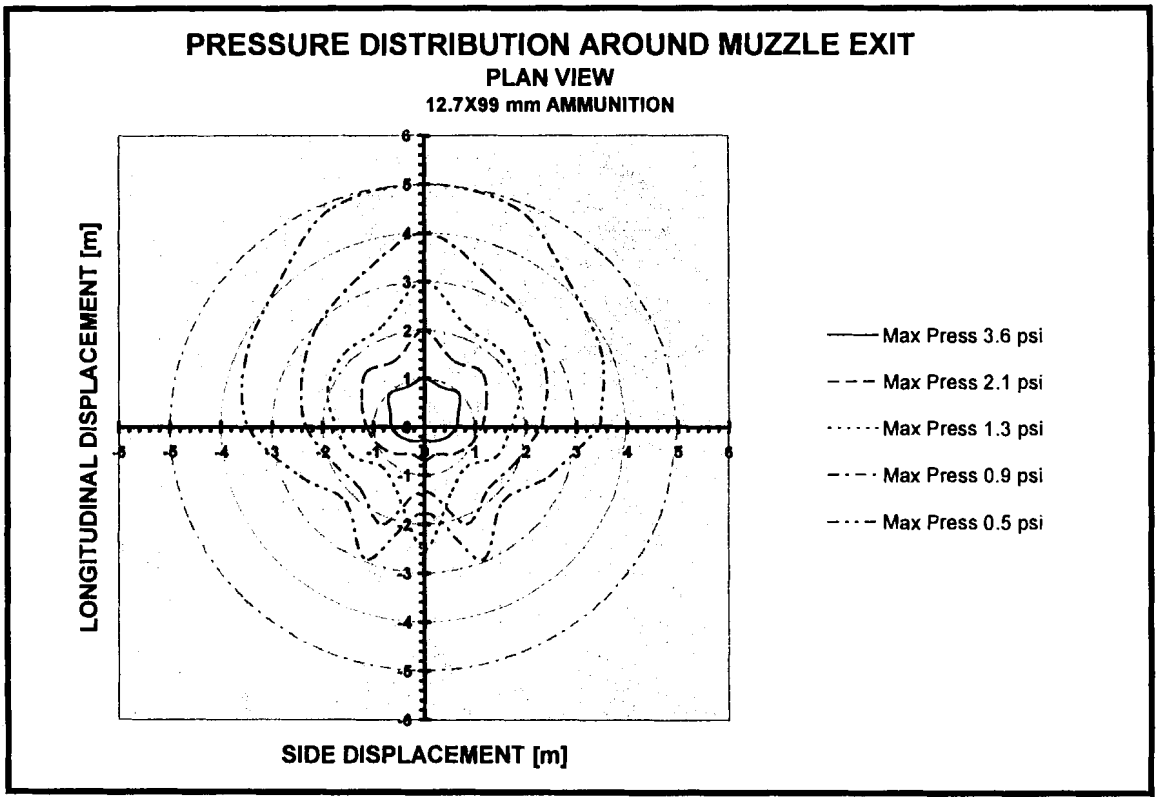
RÖHRS

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Dr. Werner Röhrs K.G.
Sonthofen/Allgäu
Tel. 08321/614-0
Fax. 08321/614-139

Zchng.-Nr. F - 13332
Artikel-Nr. 0
Ersatz für
Ersetzt durch

3) Measured Muzzle Brake Blast Profile



N. AIRBUS 380 PRESS RELEASE

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Airbus Extends Strategic Partnership with MSC.Software to Improve Virtual Product Development Process

Extension of Strategic Partnership Enables Airbus Engineers to Benefit from Expanded, Flexible, and Cost-Effective Access to Simulation Software Solutions through the MSC.MasterKey Licensing System

SANTA ANA, Calif. - November 1, 2005 - MSC.Software Corp. (OTC:MNSC) the leading global provider of Virtual Product Development (VPD) solutions including simulation software and services, today announced that Airbus, global manufacturer of commercial and military transport aircraft, extended their strategic partnership with a multi-million dollar agreement. This strategic partnership enables Airbus engineers to utilize a comprehensive range of products from the MSC.Software portfolio under the MSC.MasterKey system.

"We are very pleased and honored that Airbus has chosen MSC.Software as its strategic partner for Virtual Product Development (VPD) Solutions," said Bill Weyand, chairman and CEO, MSC.Software. "MSC's SimOffice, which is an open standards based tightly integrated suite of simulation software solutions, coupled with MSC.MasterKey gives Airbus engineers the best of both worlds - a unique Aerospace solution along with this industry's best licensing system. With the new expanded Alliance Partnership, we are confident that Airbus engineers around the world will realize new levels of functionality, flexibility, and an integrated suite of solvers. We look forward to expanding our long term partnership with Airbus."

Since the introduction of the A300 in 1974, Airbus has gained a worldwide reputation for innovation, today producing 13 aircraft models, from the 100-seat A318 jetliner to the 555-seat A380. With enterprise wide, multi-disciplinary simulation requirements, and the lifecycle of aircraft extending for decades, engineers at Airbus require a broad and integrated virtual product development solution capable

of meeting their needs for years to come.

MSC.MasterKey is a flexible solution for manufacturing organizations requiring single source access to a diverse range of VPD solutions. MSC.MasterKey allows customers to replace individual product licenses with software tokens, providing access to multiple simulation software tools, on demand. The agreement concludes an extensive technology and business value evaluation, and Airbus engineers across Europe will benefit from a full range of stand-alone and CAD-embedded simulation tools from the SimOffice and SimDesigner product suites.

"Strong, close, and long-term partnerships with enterprise level organizations such as Airbus are central to our philosophy of customer driven product development, and highly targeted service delivery. The extension of our relationship with Airbus is a further confirmation of the business benefits which MSC.Software products, licensed via MSC.MasterKey, bring to the global aerospace market", Amir Mobayen, MSC.Software, Senior VP, EMEA (Europe, Middle-East & Africa)

About MSC.Software Corporation
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