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A SHOT ACCURACY MODEL FOR PREDICTING THE FIRING PERFORMANCE OF A DIRECT FIRE WEAPON SYSTEM

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DERA performs research into the accuracy of various weapon systems for the UK MoD and has developed a Shot Accuracy Model (SAM) to simulate the complete 'breech-to-target' motion of the projectile. The suite is used to gain a greater understanding into the performance of current and future ammunition and gun system combinations. Knowledge gained from the models is used to influence gun and ammunition design and to reduce the dependency on costly firing trials.

The main areas that are modelled are: internal ballistics, in-bore gun dynamics, sabot separation, free flight dynamics and vehicle platform motion. Modification of these individual programs has also been undertaken to incorporate a stochastic ('Monte Carlo') simulation phase to better predict accuracy and dispersion effects of the projectiles at the target. The SAM is designed within a Microsoft Access® database running within the Windows NT® operating system. Its structure allows for the introduction of further modules, e.g. barrel wear, 2D internal ballistics etc. It also has links into other commercially available software, namely Graphics Server®, Matlab® and visualNastran Motion®, which are used as pre- and post-processing tools.

INTRODUCTION

The Defence Evaluation and Research Agency (DERA) has conducted applied research for the UK Ministry of Defence over many years into the accuracy and consistency of conventional gun systems and projectiles. One strand of this work investigates the in-bore dynamics of the system using the gun dynamics codes such as SIMBAD [1]. Work over the last 10 to 15 years [2-4] has shown that the prediction of accuracy and consistency of a gun-fired projectile is dependent on all aspects of its journey to the target. A complete 'breech-to-target' simulation was recommended as far back as 1992 [5].

Work within Key Technical Area (KTA) 2-11 of Weapons Technical Panel (WTP) 2 of 'The Technical Co-operation Programme' was completed in 1995. This took the key stages of the projectile dynamics of a 105mm APFSDS projectile and simulated them separately, using data from one simulation to feed into that of the other [6]. Comparisons were made with experimental results, which showed some good correspondence.

It was felt by DERA, that the concept was worth taking further and funding from the UK MoD was used to develop a 'breech-to-target' model for use with the Challenger 2 gun system. This was named the Shot Accuracy Model' (SAM). The SAM is a gun accuracy simulation tool

which attempts to predict the motion of projectiles from propellant ignition to terminal strike on target.

INITIAL INVESTIGATIONS

Preparatory work was initially undertaken to look at currently available software. Funding was not available to allow for the development of code completely from scratch. It was therefore necessary to choose existing code, which had already been validated in some fashion.

Some necessary requirements were laid down prior to choosing these codes. The main criterion was that the SAM should run on a PC with x86 processor using the Windows NT4 operating system. This meant that the chosen codes would also have to run on this system without the need for extensive rewriting. Another requirement was that the code should be non-system specific, i.e. as far as possible, models of various gun systems and projectiles could be created with relative ease without the need for time consuming set-up.

Finally, the overall solution time was required to be relatively low, i.e. less than one hour per run for a standard model, as it was envisaged that the use of a stochastic element to the models using multiple runs would be required. The packages that were finally used for the SAM are as follows:

- SIMBIB (internal ballistics) [1]
- SIMBAD (internal gun dynamics) [1]
- AVCO/SACT (sabot separation) [7]
- SIXES (free flight dynamics) [8]
- SIMVED (vehicle dynamics) [9]

SAM DESIGN

The SAM was developed under a contract for DERA by the firms of Simatics Ltd. and Danby Engineering Ltd [10]. The initial design interfaced with the first four codes listed above and was later extended to the last. To ensure that the SAM could be upgraded easily and independently of the proprietary software packages, it was decided to make it a 'stand-alone' package. The SAM interfaces with the packages through their own individual input and output (results) data files. Only if the structure of these files changed would the SAM need to be modified.

An overall structure of the SAM is shown in the Figure 1. The core of the SAM was developed in Microsoft Access 97 using two databases. The first database was for the user interface and the second for storing input data. Input data for each of the external proprietary software packages is stored in the SAM database for recall at a later date. Each data set has its own unique user defined name. This input data can be edited or deleted.

The SAM contains its own graphics routines using the Graphics Server software that the user can modify as required. The internal graphing routines will allow the SAM to plot graphs to a set format. This format can be changed by the user interactively to set such parameters as the axes scale and text, the graphs labels and the curves properties, for example smoothed lines, point markers etc. The individual proprietary software packages generate their own output files in their native formats. This allows the individual packages to be used

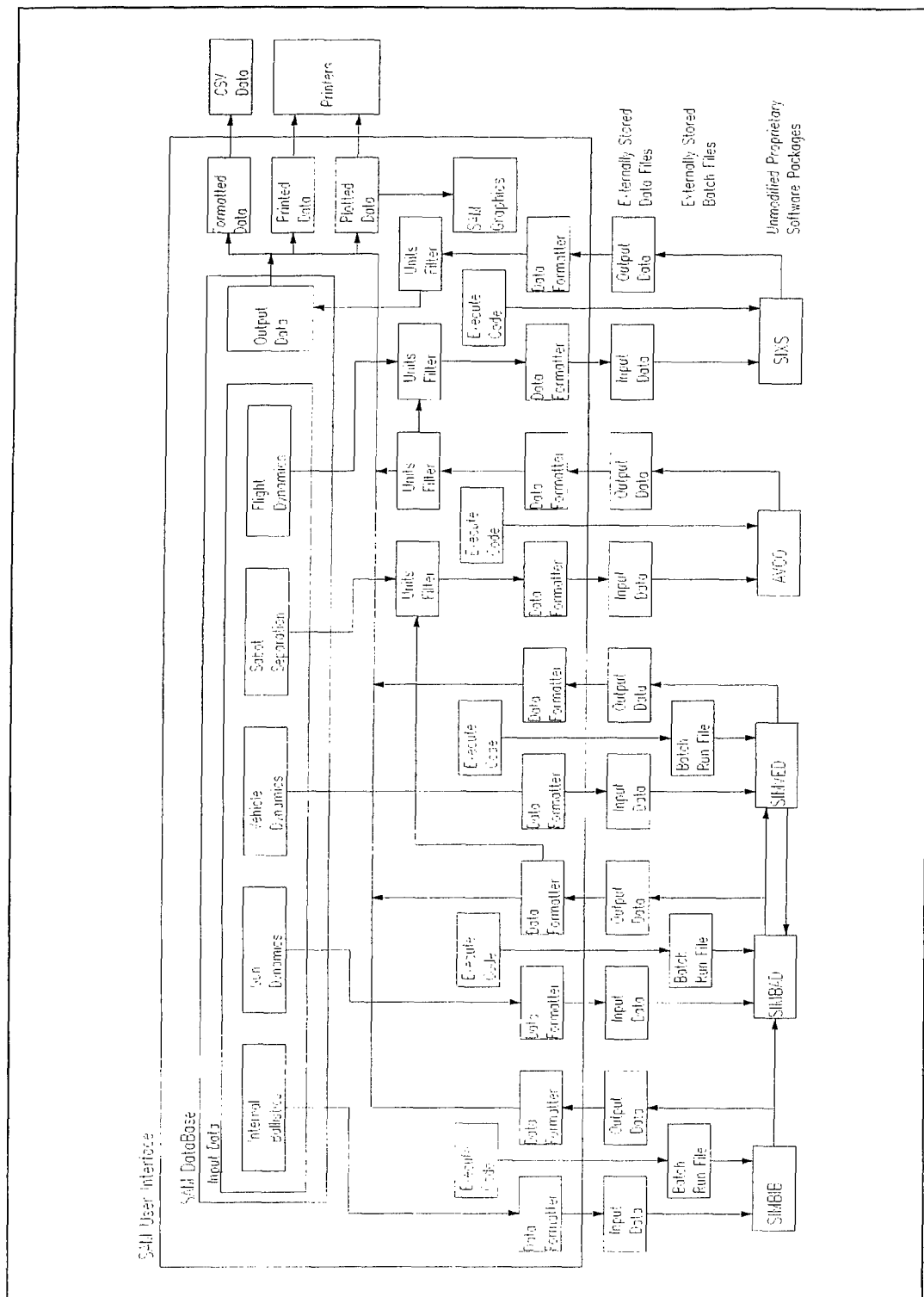


FIGURE 1. Overall structure of Shot Accuracy Model.

to post-process their own results external to the SAM if required. The SAM can also read these output files, by reformatting them and converting the respective units into those used by the SAM.

SIMBAD and SIMBIB both use Standard International (SI) units, which were used as default in the SAM. However, the data structure for the input files still needs to be defined, so the SAM formats the data to produce compatible data files for both SIMBAD and SIMBIB. When the user wishes to run SIMBAD or SIMBIB, the input data stored in the SAM database is formatted into the required format and a data file is generated and stored on disk. A batch run file is also generated and stored on disk. SAM issues an execute command that loads the required program (SIMBAD or SIMBIB) and informs the program which batch file to run. The batch file includes the information as to which data files to use for the analysis. The program runs normally and generates a results file (output file) that has been defined in the batch file. Once the program has completed the analysis and results storage, control is passed back to SAM. To post-process the results from SIMBAD or SIMBIB in the SAM, the output data files from SIMBAD or SIMBIB have to be read and formatted. The SAM contains the data formatter to do this and offers the user a variety of output options.

The SAM user interface to AVCO/SACT is similar to that of SIMBAD/SIMBIB. The differences are that the input data has to be converted into the units required by AVCO prior to SAM formatting its data to be compatible with AVCO/SACT, since AVCO/SACT uses mainly imperial units. Also when reading the output files from AVCO/SACT, after SAM has formatted them, they are passed through a units filter to convert the results into the units (metric) used by the SAM (See Figure 2). AVCO/SACT can be run directly without the need of a run batch file. The "Execute" command is sent directly to AVCO/SACT from the SAM. The SAM user interface to SIXS is identical to that between the SAM and AVCO/SACT.

SAM - Units Specification					
		Delete Record	Main Menu		
Find parameter	Mass	Description	pounds		
	Description	Acronym			
Standard	kilogrammes	kg			
		Multiply by	Divide by	then Add	
Non-Standard	pounds	lb	0.4535924	1	0
Example	1	lb	=	0.4535924	kg
Units library	Description	Acronym	Multiply	Divide	Add
	grammes	g	1	1000	0
	Hundredweight	cwt	50.8023	1	0
	kilogrammes	kg	1	1	0
	pounds	lb	0.4535924	1	0

FIGURE 2. Example of the Units specification form for the 'mass' parameter.

The SAM user interface consists of a number of different input and utility forms. A main menu form controls the access to subsequent forms (See Figure 3), making the system logical to use and follow.

General	Data Input	Analysis
About SAM	INTERNAL BALLISTICS	ANALYSIS SET-UP
DEFAULTS	GUN DYNAMICS	ANALYSE
UNITS	SABOT SEPARATION	PLOT RESULTS
EXIT SAM	FLIGHT DYNAMICS	
	VEHICLE DYNAMICS	

FIGURE 3. Main form of the Shot Accuracy Model.

The graphics output from the SAM has been developed using Graphics Server. The reason for this is that Graphics Server is much faster than Microsoft's Graph 5 and is more flexible. Graphics Server allows for a high degree of user modification of the final graphic presentation, without the need to change the graphs at a developers level.

The User Defined Routines of SIMBAD are not directly accessible through the SAM. It is however possible to modify the SIMBAD User Defined Routines, compile them external to the SAM and then run this modified version of SIMBAD from the SAM. It should also be noted that if user defined outputs are defined in SIMBAD User Defined Routines, then these currently would also not be automatically picked up by the SAM.

ANALYSIS CONTROL

The SAM presents the user with an analysis selection form (See Figure 4). All types of analysis are offered to the user, internal ballistics, gun dynamics, sabot separation and flight dynamics. If the user selects one of these analysis types, a selection box becomes visible that offers the user a choice of proprietary software for that analysis. Another selection box also becomes visible, where the user can then select the input data set required for that analysis.

If internal ballistics was chosen, then the sabot separation and flight dynamics options is 'greyed' out and not be selectable by the user. This is because the output from an internal ballistics analysis would not present the correct or sufficient information for these other two types of analysis. Deselecting internal ballistics in this instance would then automatically allow the user to select any one of the four analysis types.

Having selected internal ballistics analysis type, if the user then selects gun dynamics, the other three options automatically become selectable as flight dynamics is an allowable selection without sabot separation and vice versa. Once the analysis selection has been made, the analyse button is clicked and the SAM will control the whole process, running the selected analyses in the required order and passing the relevant data from the SAM database and any output from a previous analysis. For example, pressure time curve and shot acceleration data from SIMBIB into SIMBAD.

The screenshot shows a window titled "SAM - Analyse Setup". At the top, there are buttons for "ANALYSE", "Delete Record", "RETURN", and a "New" button with left and right arrow icons. Below these, there are two tabs: "Analyse" (selected) and "Manual Example". The "Analyse" tab contains a "Title" field with the text "Manual Example Title". Below the tabs, there are two main sections: "Application Selection Setup" and "SIMBAD Analysis Controls". The "Application Selection Setup" section contains a table with five rows, each representing an application and its associated analysis type and status.

Application		
Internal Ballistics	SIMBIB	☒
Gun Dynamics	SIMBAD	☒
Sabot Separation	SACT	☒
Flight Dynamics	SIXS	☒
Vehicle Dynamics	SIMVED	☒

The "SIMBAD Analysis Controls" section contains a table with five rows, each representing an analysis type and its associated data source.

Analysis data	
SIMBIB	Manual Example
SIMBAD	Manual Example
SACT	Manual Example
SIXS	Manual Example
SIMVED	Manual Example

FIGURE 4. Analysis selection form.

RESULTS OUTPUT

The SAM calculates the mean point of impact (MPI) for a particular weapon system from the output of SIXS. This is displayed graphically and indicate numerically to an accuracy of two decimal places the MPI.

The SAM includes a graphics form that enables one selected variable from a drop down list of variables to be plotted against one or more variables selected from another drop down list of the same variables. This method offers the greatest flexibility in that there is no limitation on the variables selected to plot against each other. It is then up to the user to select what plots are most meaningful to them.

FURTHER ENHANCEMENTS

To obtain predicted values of MPI and dispersion from a model such as the SAM requires that a stochastic component be included in the calculations. This solution has been partly attained by the inclusion of a 'Monte-Carlo' type simulation within SIMBAD using the 'user defined routines' and the writing of additional code.

For a given gun system, each input parameter within SIMBAD is assigned a Standard Deviation (SD) about the baseline value that appears in the input file. Standard SIMBAD multiple run files are used to run the data through SIMBAD numerous times. Prior to each run, a pseudo-random routine regenerates the input data based on the SDs and baseline values. An example of the output from such a study is given in Figure 5 below. An extension of these principles to the other components in the SAM suite has yet to be achieved.

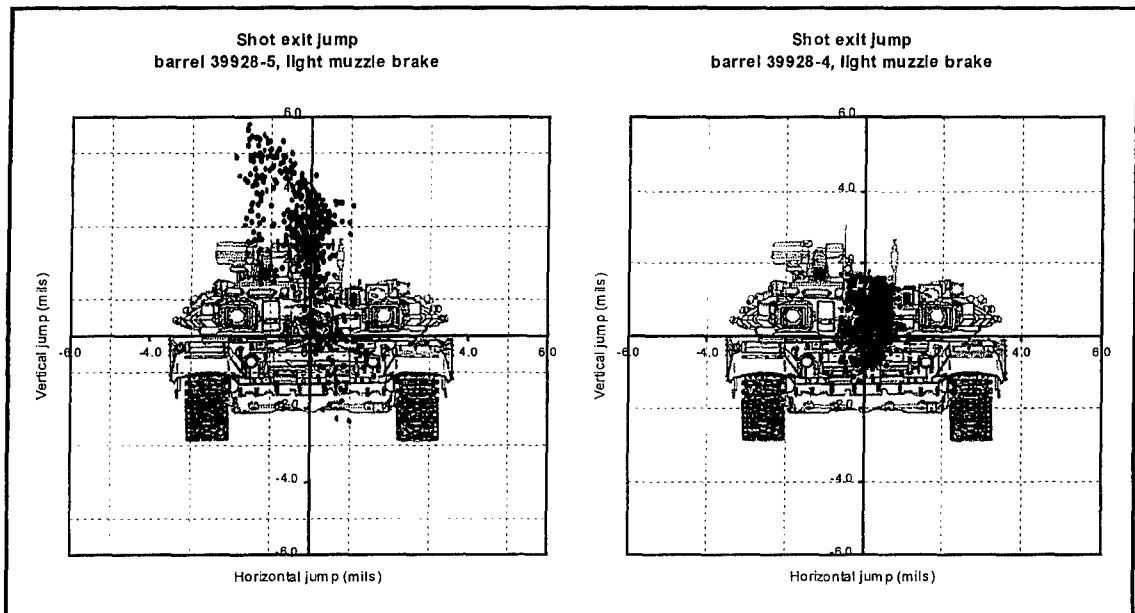


FIGURE 5. Example of predicted shot jump using 'Monte-Carlo' techniques within SIMBAD.

LINKS TO OTHER PACKAGES

No direct links exist with other packages at this moment in time. However, some initial steps have been taken to investigate linking both the input and output to the following:

- *Matlab*: mainly for use in converting results to obtain frequency response.
- *Solid Edge CAD*: used to automatically generate SIMBAD input files for the barrel, cradle, penetrator and sabot from solid model equivalents.
- *Algor FEA*: import SIMBAD input files for the barrel, cradle, penetrator and sabot. Automatically generate FEA models for obtaining natural frequencies and mode shapes. Import SIMBAD results files for stress analysis of projectile designs.

visualNastran Motion: automatically import relevant Solid Edge projectile model and SIMBAD results for visual post-processing purposes.

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