

**Project MMS2
Report No 3**

**Towards a Standard Qualification
Plan (SQP) for Composite Materials
- Current Status of Material Property
Databases**

M R L Gower and G D Sims

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**M R L Gower and G D Sims
NPL Materials Centre
National Physical Laboratory
Teddington, Middlesex
TW11 0LW, UK**

ABSTRACT

It is widely accepted that there is a need for generic composite materials data suitable for materials selection and initial design. In the DTI funded programme Measurements for Materials Systems (MMS), work has been undertaken with the objective of producing a Standard Qualification Plan (SQP) aimed at increasing the amount and availability of traceable materials data, and reducing the costs involved with qualification of fibre-reinforced plastic composite materials.

In order to ascertain how the data generated by the SQP will be included in existing material databases, a survey of the current status of prominent material databases has been carried out and is detailed in this report. In addition, the progress that has been achieved through the SQP initiative is described and recommendations are provided as to the most appropriate format for release of the SQP generated data.

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National Physical Laboratory
Teddington, Middlesex, UK, TW11 0LW

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Head of NPL Materials Centre.

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1. INTRODUCTION

From discussions with industry contacts and surveys undertaken as part of previous programme formulation exercises, it is evident that there is still a need for generic composite materials data suitable for materials selection and initial design. The availability of such data would allow considerable progress to be made in deciding on the type of material, section thickness etc., that should be chosen for a design, whether by using first principle equations, PC software packages or a detailed finite element analysis (FEA). The finalisation of a design requires a full set of information on the latest materials (e.g. cost, processing options, surface finish etc.) and it would be necessary to approach the suppliers of the identified candidate material type(s) to obtain such information.

There are several reasons for this lack of baseline or generic data including the wide range of materials feasible in composites (e.g. fibre and resin types and formats) and the variety of test methods available that can be used for generating such data. This has resulted in few sets of reference data of known pedigree and reliability being available, however, the number of test methods is successfully being reduced to single, harmonised international standards through work such as that funded under DTI materials measurement programmes.

In the current DTI funded programme (Measurements for Materials Systems (MMS)), work has been undertaken with the objective of producing a Standard Qualification Plan [1,2] (Project MMS2 - "Towards a Standard Qualification Plan (SQP) for Composite Materials") aimed at increasing the amount and availability of traceable materials data, and reducing the costs involved with qualification of fibre-reinforced plastic composite materials. It is envisaged that the widespread use of the SQP document will lead to a reduction in qualification costs, and an increase in the consideration and use of composites in new applications.

In order to ascertain how the data generated by the SQP will be included in existing material databases, a survey of the types of databases and the current status of prominent material databases has been carried out and is detailed in this report (Sections 2/3). Section 4 describes the progress achieved through the SQP initiative and Section 5 gives conclusions and recommendations.

2. DATABASE FORMATS AND STANDARDISATION

There are several levels or types of databases and database activities as summarised in Table 1 Appendix 1, with considerable overlapping of features. These range from small databases prepared by most engineers using software products on their own PCs, to extensive systems where all data and support information is held centrally, with all or some of the data approved for use in design. In at least one case only this centrally approved data may be used in design solutions. Table 1 reviews the different formats available in conjunction with some typical examples available, the support platforms required, the degree of standardisation and some basic characteristics.

There are two levels of standardisation that are relevant. Firstly, the test methods used to generate the recorded data. These are increasingly referenced by materials suppliers, industrial companies and test laboratories resulting in an improvement in the quality of available databases. Academic researchers have been slower to record in detail the methods used or to use standard test methods. However, following prompting from the National Physical Laboratory (NPL) as part of past DTI programmes, the adherence to good practice is increasing. Intrinsic to the use of the measured data is adequate and traceable identification and characterisation of the material tested. Properties such as the fibre volume fraction (V_f) and glass-transition temperature (T_g), as well as being required in their own right should also be recorded to assist interpretation of other data (e.g. mechanical properties).

The second level of standardisation relates to the database structure itself. In general, the level of standardisation and the application of standardised formats are lower than for test methods. There are two main strands to standard formats within the ISO (International Organisation for

Standardisation) system. Firstly, there is the standard format produced initially for engineering polymers including filled systems, now re-numbered as Part 1 of ISO 10350, that was based on prior NPL and British Plastics Federation work as a national standard. This was developed as an international standard with a UK project leader at NPL, alongside a commercial database (CAMPUS), driven by major global polymer suppliers. More recently, again drafted at NPL, Part 2 has been prepared for long fibre composites. Long-fibre systems are those manufactured from materials with fibre lengths greater than 7.5 mm in the starting compound/prepreg in both thermoset and thermoplastic based systems. These two parts are aimed at producing technical datasheet type information on a strictly comparable basis whereby options in test methods are pre-selected. Part 2 introduces in-plane anisotropy in the properties. It covers physical, mechanical, chemical and electrical properties. This standard format contributed to the SQP format.

The second strand highlights the need for databases to achieve their full usefulness through integration or compatibility with other engineering software packages (i.e. FEA, computer aided design (CAD), NMC packages) operated by different organisations. Measures to overcome compatibility and electronic data transfer problems have been put in place through the introduction of the Standard for the Exchange of Product Model data (ISO 10303) or STEP. STEP has been developed with the intention of easing data transfer between computer systems (N.B. this is appropriate as the majority of end-users of composite data are traditionally PC users). ISO 10303 is a collection of standards and the “Integrated Generic Resource Models”, Parts 41-49, facilitate common structures for the data e.g. geometry, product description, material properties etc. These parts are then incorporated into “Application Protocols” or APs. The APs are themselves standards, which state that when data is exchanged for a particular application, the data should be arranged in a certain manner using the agreed terminology and format. In addition to STEP, interdisciplinary scientific committees such as CODATA (Committee on Data for Science and Technology), have been established with the objective of improving the quality and accessibility of data, as well as the methods by which data are acquired, managed, analysed and evaluated.

Within the ASTM series of standards produced by the D-30 committee there are three database related standards. One of these, ASTM E 1309, provides a comprehensive guide to the identification of composite materials in databases but does not provide a database itself or material properties. Further work in the USA is discussed below related to the M-Vision commercial database.

3. REVIEW OF MATERIAL PROPERTY DATABASES

This section reviews the current status of leading composite material and plastics/polymers property databases.

3.1 MIL-HDBK-17 - Composite Materials Handbook

The composite materials handbook acts as a general technical reference guide for polymer matrix composites and consists of 5 volumes; Volume 1 provides guidelines for the characterisation of structural materials [3], Volume 2 - material properties [4], Volume 3 - materials usage, design, and analysis [5], Volume 4 - Metal Matrix Composites and Volume 5 - Ceramic Matrix Composites. Volume 1 details recommended test methods and practices by which material property data should be obtained, and criteria for their acceptance for publication. Data obtained and selected according to the test methods and procedures provided in Volume 1 are published in Volume 2. The materials considered in the handbook are continuous fibre-reinforced polymer matrix composites.

The materials data in Volume 2 are divided into chapters for fibre, resin and composite material properties and are presented in standard formats. The handbook includes data sets for 33 carbon fibre-reinforced composites and 3 glass fibre-reinforced composites, and a number of physical and mechanical properties are provided.

3.2 M/VISION Composite Material Schemas

M/Vision is a data storage system that uses a user defined hierarchical interface which can be designed to display materials information. The materials data generated from tests usually has data and information associated with it and often a complex pedigree. For example, the tensile strength of a composite should be associated to the shape of the test specimen, the form of the material from which it was cut, the standard used for the test, the processing route for the material etc. All of these attributes describe a particular composite specimen in tension and together describe its history. M/Vision provides flexibility by allowing storage and links between significant quantities of metadata. Further, the hierarchical nature of the database software presents this information in a common format for the user.

A 'schema' or 'define' file is the skeleton used by M/Vision to create a database and contains all the items required for the materials system. This includes attributes for tensile, compressive, flexural and shear modulus. Similar descriptors are needed for strength, stiffness, Poisson's ratio and items such as the processing method or associated products. All attributes in the schema are defined as part of their hierarchy within the database and also are given abbreviated names and a general description. It includes the SI units and number of decimal places for presentation, where relevant.

A good deal of work has been completed on composite material schemas and this has led to the production of a Composite Material Test Data Schema (CMTDS) created by the Database Schema Development Committee for Composites (DSDCC). The CMTDS is an industry standard, ASTM/MIL-HDBK-17 compliant schema and was built on previous work of the design committee, while incorporating parts from ASTM E-49, ASTM D-30 and MIL-HDBK-17. The schema is provided gratis to the composites industry. There are at present 555 attributes and another 49 graphs in 10 relations within CMTDS and, in addition, an appendix holds 386 proposed non-mechanical attributes with 7 graphs. Although comprehensive, the size of this schema makes it difficult to be effectively edited for use by a small organisation only requiring limited parts of the schema.

In addition to the CMTDS, there are a number of more 'user friendly', less extensive alternatives. The MIL-HDBK-17-2E standard databank produced by Material Sciences Corporation is essentially an electronic version of the military handbook and contains 137 material records extracted from Chapters 4 and 10 of the handbook. The PMC 90 [6] Advanced Polymer-Matrix Composites databank is produced by the University of Dayton Research Institute and contains several tables and graphs for 10 composite materials. The databank contains mechanical and thermal constants as well as temperature and strain-dependent data. A number of the materials contain sufficient properties to create material models for analysis programs (i.e. FEA).

3.3 CAMPUS/FUNDUS

Since the launch of CAMPUS in 1988, this worldwide grade-specific, searchable database for plastics has become a world leader. CAMPUS was developed through cooperation between several leading plastics producing companies (e.g. BASF, Bayer, Hoescht) and allows the user to perform pre-selection and screening of a wide range of commercial grades of plastic. At present, more than 50 plastics producers use the database to distribute free product information to their customers. It is PC based and uses a uniform database and interface structure for all participating organisations. Each producer distributes the database (on a disk or downloadable from respective web-sites) which details the company's specific products. The database also has associated software that allows the user to perform searches. In addition, the M-Base company provides software (MCBase® 4.5) that allows the user to load CAMPUS data from different suppliers into one database allowing direct comparison of thousands of grades of plastics.

CAMPUS is based on three international standards for comparable single-point and multi-point (mechanical and processing) data [7-9] authored at NPL with close cooperation with the developers of the CAMPUS database. The database represents an application of these standards in that CAMPUS uses data tables which closely resemble those prescribed in the standards and strictly

adheres to the ISO standard property definitions. The material properties included in the database are generated, where possible, using ISO standards providing clear specification of specimen types and dimensions, and conditions for processing, manufacture and testing. CAMPUS provides values for over 100 material properties.

FUNDUS is a database for long-fibre reinforced sheet moulding compounds (SMC), bulk moulding compounds (BMC) and glass-mat thermoplastics (GMT). The database is supplier-specific and is distributed free of charge. The structure and function of FUNDUS is essentially the same as CAMPUS and is supported by more than 10 material suppliers.

In addition to CAMPUS and FUNDUS there are a number of other grade-specific databases such as Selector II, Plaspec and CenBASE/Materials.

3.4 PLASCAMS

In contrast to the approach used in databases such as CAMPUS, where material selection is predominantly made on the values of a range of properties, PLASCAMS is a knowledge based system (computer aided materials selection package) that covers all the main issues in material selection and simulates the selection procedure that might be used by a materials expert. It contains 351 different materials (thermosets and thermoplastics), each having a data file containing values for 65 properties and processing ranges and 193 chemical environments. The approach recommended by PLASCAMS is to use the knowledge base to identify a suitable material for a particular application and then use a grade-specific database (e.g. CAMPUS) to identify the most suitable grade of material and supplier. The package also allows comparisons between and searches on material properties.

The data sheets in PLASCAMS provide typical properties for generic types of material and are not specific to a particular grade. Data are based on measurements conducted according to a variety of national and international standards, with no individual standards organisation being favoured. It is stressed that the material data provided by PLASCAMS is not to be used for design purposes.

3.5 CES4

CES4 is a family of products that relate to databases and data handling requirements marketed by Granta Design Ltd. The four primary modules are:-

- CES Selector - for analysis /modelling
- CES Constructor - for consolidating materials information from different sources
- CES Lab - for lab test management
- CES Web - for material information dissemination.

These facilities are supported by Granta Design's Materials Data Network (www.matdata.net), which provides access to several "partner" supplied databases such as the American Society for Metals (ASM) handbook and the NPL MIDAS Database (<http://midas.npl.co.uk/midas/index.jsp>).

CES Selector uses the latest version of the Cambridge Engineering Selector (CES), developed by Granta Design Ltd from the earlier work by Professor Mike Ashby and colleagues at the University of Cambridge, UK. In the standard version of CES, materials are grouped into seven basic categories including polymers and composites. The data is presented in materials selection charts that combine materials data with simple geometrical models to graphically illustrate relationships between various material properties. The database not only includes data for over 3,700 materials, but also data on 240 manufacturing, joining and finishing processes.

Various add-on options are available. The CAMPUS database can be used in conjunction with CES and the MIL-HDBK-17-2E database supplements the generic composite grades available in CES,

with all of the detailed industry-standard design data for the aerospace grade advanced composites contained in the handbook. Most of the data is also available as a function of temperature, which can be plotted interactively and used for material selection purposes.

An alternative web-based composite database “MATDAT” will shortly be available as part of a web portal developed by several DTI material measurement contractors (i.e. AEAT, MERL, Qinetiq etc) led by NPL. The database module has been prepared by Qinetiq, and is based on assessment of the traceability and reliability of the data. Much of the data is drawn from work funded by the UK government, principally the Department of Trade and Industry.

3.6 CoDA

CoDA (Component Design Analysis) is a PC based software package that assists in the preliminary stage of engineering design of polymer matrix composite structures. It has been developed at the National Physical Laboratory (NPL) in conjunction with industry over a number of years. The CoDA software package consists of several modules that can be used in the design of materials, laminates, panels, beams and bolted/bonded joints.

CoDA contains a material synthesiser module, which allows for the automatic calculation of composite material elastic and hygrothermal properties based on user-defined fibre and resin properties. More specifically, mechanical properties in CoDA can be defined (and stored) either at the material level (isotropic, or orthotropic and possibly incorporating fibres and resin, thus not requiring the synthesis of properties), or at the fibre and resin levels. The latter two can then be combined to form a material for which the properties are calculated. Parameters such as fibre volume fraction and type of reinforcement are taken into account. Both continuous and discontinuous reinforcement can be analysed in a fixed or random orientation, and the materials which can be synthesised vary from thermosetting moulding compounds to aerospace pre-pregs. The software computes the thermal and moisture expansion properties as well as the stiffness and strength properties in the three principal directions. The synthesised properties can be used in the other CoDA modules or in external design packages, such as finite element software.

Although CoDA is not a stand alone material properties database, a range of material properties are and can be stored for several materials. Figure 1 shows the format of the material properties (fully 3D) sheet for a material ‘synthesised’ from a combination of fibre and resin. These properties are then used in other modules of CoDA for the design of laminates, panels, beams and joints.

4. STANDARD QUALIFICATION PLAN (SQP)

The overall objective of project MMS2 was to produce an SQP [1,2] aimed at reducing the costs involved with composite materials qualification and increasing the availability and amount of traceable materials data. The SQP is aimed at satisfying the minimum common requirements necessary to allow initial material selection, quality control and preliminary design to be undertaken. Further qualification requirements, not met by the minimum SQP, are included in an Extended Qualification Plan (EQP) (included as part of the SQP procedure).

After extensive consultation with industry, a draft SQP [1] was produced containing physical/chemical tests for cured and uncured properties, and basic and ‘building block’ mechanical tests for cured material properties. Standard conditioning and test temperatures/humidity levels were recommended. The production of the SQP was, where possible, based on ISO standards including test plate manufacture (ISO/FDIS 1268) and harmonised ISO mechanical, thermal and physical test methods. The SQP procedure provides guidance on test method selection, test matrices and sampling, panel/specimen preparation and machining, statistical analysis, and presentation of results.

Properties		Parametric Analysis	
Property	Value		
Vf (%)	18.600		
n1			
n2			
Fibre Length (µm)	1399.000		
SYNTHESISED			
Density (kg/m³)	1404.120		
E11 (GPa)	13.378		
E22 (GPa)	4.482		
E33 (GPa)	4.482		
G12 (GPa)	1.844		
G13 (GPa)	1.844		
G23 (GPa)	1.844		
ν12	0.363		
ν13	0.363		
ν23	0.274		
ν21	0.109		
ν31	0.109		
ν32	0.274		
α11 (/10⁶ °C)	18.372		
α22 (/10⁶ °C)	97.584		
B11 (/10⁸ %M)			
B22 (/10⁸ %M)			
S11T (MPa)	242.852		
S22T (MPa)	38.952		
S33T (MPa)	64.920		
S11C (MPa)	574.904		
S22C (MPa)	181.521		
S33C (MPa)	170.000		
S12 (MPa)	61.250		
S13 (MPa)	37.417		
S23 (MPa)	37.417		
Critical Fibre Length (µm)	204.781		

Figure 1 - Material properties as stored in CoDA software material property database

Following a similar approach to that used by the CAMPUS database, the SQP is based on the format of ISO 10350-2 [10]. Tables 2 and 3, Appendix 1, provide examples of the format of batch requirements and a corresponding results sheet for cured mechanical properties included in the SQP.

The draft document was widely disseminated to industry for comment and the SQP was then finalised [2], taking into account suggestions from industry. In addition, over 100 copies were downloaded from the NPL Composites web site. Overall the feedback received from industry was positive and it was felt that the SQP was a useable and useful tool for materials qualification. The results of a validation round-robin exercise [11] demonstrated the robustness and suitability of selected test methods in the SQP and will generate confidence in use of the SQP.

Discussions with the Civil Aviation Authority (CAA) [12] have indicated that a reduction in the amount of materials qualification testing and increased sharing of data between organisations has already been achieved in the USA, through the introduction of a similar qualification plan [13] approved by the Federal Aviation Administration. It is envisaged that widespread use of the SQP procedure will similarly reduce the volume of qualification testing and increase the amount and availability of composite material property data. This will in turn aid designers and end-users, and encourage the increased and new use of composite materials.

5. DISCUSSION AND RECOMMENDATIONS

The data generated by the NPL developed SQP, can be included in several of the databases reviewed in this report. The SQP generated data would not fully populate some databases (i.e. CMTDS), whilst for others (i.e. CoDA) there would be too much data. It is noted however, that the CoDA database could easily be expanded to include other properties currently not listed. It is considered that at this stage of the development of the SQP procedure, the most appropriate format for release of the data would be in the form of that presented in the results sheet of Figure 2 and similar to that released by the organisations contributing to the popular CAMPUS/FUNDUS database. The SQP and CAMPUS/FUNDUS initiatives are both based on ISO 10350 and as such share a similar structure.

From the conclusion of the MMS2 project, two aspects of further work have been identified. A key area is to ensure further support and collaboration with national and international regulatory bodies (e.g. CAA and FAA) to encourage widespread use of the SQP in industry, and achieve harmonisation of material qualification initiatives. This could possibly be achieved through the international pre-normalisation VAMAS (Versailles project on Advanced Material and Standards) initiative. Industry in other sectors have indicated their interests in developing qualification plans for other types of composite materials relevant to their industries (e.g. general automotive, c.f. motorsport).

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APPENDIX 1

Table 1 - Simplified analysis of database types and features

Database Type	Platform	Examples	Standardisation	Characteristics
User prepared	MS Excel or Access on Windows PC	Most engineer's PCs	None normally	Limited search facility, Generally not comprehensive
PC based software	Windows PC/C+	Associated with another product, e.g. CoDA design and synthesis modules	Limited	Supports main product, user inputs and or synthesised data, listing as only search facility, integrated into design modules, output
CD based	Windows PC	Single company disc – e.g. SP Systems	None	Normally via product categories, some may include search facilities.
	Windows PC	Multiple company system – e.g. CAMPUS, FUNDUS	Test methods and definitions tied to ISO standard 10350 and 11403.	Associated software to allow user searches across different suppliers discs (also moving to web based versions)
Web enabled	Internet access PC	Web versions of CD systems Free standing databases – e.g. CES4/Matdat/PLASCAMS/MaterialSolutions	Varies from none to fully referenced for individual data. Generally, no standard for data framework.	Various with product but can include name based, parameter values searches
Paper copy systems	Books, company literature	Military Handbook, most company have data sheets or compilations of datasheets.	Increasingly test method listed against data	Web available via other products (CES4/M/Vision)
Server systems	UNIX type systems	Large bespoke database products - e.g. M/Vision	None but schemas being developed by organisations such as CMTDS and Materials Science Corp.	Comprehensive facilities for storage of raw data, derived data, images. Extensive search facilities, output to FEA systems.

Table 2 - Standard Qualification Plan - Cured mechanical properties - Batch requirements

Property		Symbol	Standard	Unit	Test Condition						Test conditions and supplementary instructions	
					DRY				70°C/85% RH			
					-55°C	RT	70°C	125°C*	RT	70°C		
14	Fibre and resin volume fraction	V _f V _r	ISO 14127 and ISO 1183	%		3						ISO 1183 for density
15	Tension	σ _{Mt11}	Unidirectional BS EN ISO 527-5	MPa	1	3	1				1	Refer to standard for specimen dimensions and test details. () – not required for balanced fabrics
		σ _{Mt22}		MPa	1	1	(1)			(1)		
		E _{t11}		GPa	1	3	1			1		
		E _{t22}		GPa	1	1	(1)			(1)		
		ε _{Mt11}	%	1	3	1			1			
		ε _{Mt22}	%	1	1	(1)			(1)			
		ν ₁₂			1							
		ν ₁₃			1							
		ν ₂₁			1							
		ν ₂₃			1							
16	Compression	σ _{Mc11}	ISO 14126 unidirectional, multidirectional	MPa	1	3	1				3	Refer to standard for specimen dimensions and test details. Type A, B ₁ and B ₂ specimens, testing by Method 1 (shear loading) or Method 2 (end loading) () – not required for balanced fabrics
		σ _{Mc22}		MPa		1	(1)				1	
		E _{c11}		GPa	1	3	1				3	
		E _{c22}		GPa		1	(1)				1	
		ε _{Mc11}		%	1	3	1				3	
		ε _{Mc22}		%		1	(1)				1	
		τ _{M12}		MPa	1	3	1	1			1	
17	Shear ±45° tension	γ _{M12}	BS EN ISO 14129	%	1	3	1	1	1	1		
		G ₁₂		GPa	1	3	1	1	1	1		
		τ _{M1}		MPa	1	3	1	1	3	1	3	
18	ILSS – through thickness	τ _{M2}	BS EN ISO 14130	MPa		1	1					
		σ _{Mf11}		MPa		3						
19	Flexural	σ _{Mf22}	BS EN ISO 14125	MPa		3						Refer to standard for specimen dimensions and test details. Provide details of which method used: Method A (3 point flexure) and Method B (4 point flexure)
		E _{f11}		MPa		3						
		E _{f22}		MPa		3						
				MPa		3						
		G ₁₃		GPa		3						

N.B. * - for 180°C cure resins only

Table 3 - Standard Qualification Plan - Cured mechanical properties - Results Sheet

Property	Symbol	Standard	Unit	Test Condition												Comments	
				DRY						70°C/85% RH							
				-55°C		RT		70°C		125°C		RT		70°C			
				μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ		
14	Fibre and resin volume fraction	V _f V _r	ISO 14127 and ISO 1183	%													
15	Tension	σ _{M01} σ _{M02}	Unidirectional BS EN ISO 527-5	MPa													
					MPa												
		E ₀₁₁ E ₀₂₂		GPa													
		GPa															
		ε _{M01} ε _{M02}		%													
		%															
		V ₁₂ V ₁₃		Multidirectional BS EN ISO 527-4													
		V ₂₁ V ₂₃															
16	Compression	σ _{M01} σ _{M02}	ISO 14126 unidirectional, multidirectional	MPa													
		MPa															
		GPa															
		GPa															
		%															
		%															
17	Shear ±45° tension	τ _{M12} γ _{M12}	BS EN ISO 14129	MPa													
		%															
		GPa															
18	ILSS – through thickness	τ _{M1} τ _{M2}	BS EN ISO 14130	MPa													
		MPa															
19	Flexural	σ _{M01} σ _{M02}	BS EN ISO 14125	MPa													
		MPa															
		E ₀₁₁ E ₀₂₂															
		G ₁₃															

N.B. μ – mean, σ – standard deviation