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ULTMAT 2.1 User's Manual

Malcolm J. Smith

Defence R&D Canada – Atlantic

Technical Memorandum
DRDC Atlantic TM 2006-049
March 2006

Canada

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Abstract

ULTMAT 2.1 is a computer program developed by DRDC Atlantic for calculating the ultimate elasto-plastic bending strength of longitudinally stiffened, transversely framed ships. Version 2.1 marks a significant re-development of the code with expanded analysis capabilities over earlier versions. Version 2.1 has been implemented in the ISSMM Software Tool (IST) for rapid damaged strength assessments of the Halifax class, and can also be used in standalone mode. This document provides an expanded and updated manual for the ULTMAT 2.1 user, covering the installation and running of the program as well as preparation of input data files.

Résumé

ULTMAT 2.1 est un programme informatique qui a été développé à RDDC Atlantique afin de calculer la résistance élastoplastique définitive des navires renforcés longitudinalement et charpentés transversalement. La version 2.1 constitue une refonte importante du code avec l’ajout de capacités d’analyse plus étendues que dans les versions antérieures. La version 2.1 a été mise en œuvre dans l’outil logiciel de GAMSN (IST) afin de permettre d’évaluer rapidement tout dommage lié à la résistance de la classe Halifax. Elle peut aussi servir en mode autonome. Le présent document constitue un manuel détaillé et à jour. Destiné à l’utilisateur d’ULTMAT 2.1, il traite de l’installation et de l’exécution du programme ainsi que de la préparation des fichiers de données de saisie.

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Executive summary

Introduction

ULTMAT 2.1 is a computer program developed by DRDC Atlantic for calculating the ultimate hull girder strength of ships. Version 2.1 marks a significant re-development of the code with expanded analysis capabilities over earlier versions. It has been implemented in the ISSMM Software Tool (IST) for rapid damaged strength assessments of the Halifax class, and can also be used in standalone mode.

Results

With the information provided in this document a user of ULTMAT 2.1 will be able to calculate the ultimate hull girder strength of a ship in any bending direction, and obtain results in the form of a strength limit or envelope (interaction curve) or as a relationship between bending moment and curvature. Formatting specifications and sample data for all of the required input files are provided, as well as instructions for the installation and running of the program. Sample output data in ASCII format are also provided for several types of ultimate strength analysis.

Significance

Safe operation of a vessel depends on there being sufficient strength in the hull girder to withstand maximum or extreme sea loads. This strength, or capacity, can be degraded over time by corrosion and other types of damage. As it may be necessary to operate a vessel with significant amounts of damage for short periods of times, e.g., until it can reach a port of safety for repairs, an ability to predict accurately the damaged hull girder capacity is vital to maintaining an adequate margin of safety. Also, a damaged and partially flooded ship may not experience bending loads in the predominantly vertical direction. In this case, an ability to predict bi-axial strength (combined vertical and horizontal) is essential.

Future plans

At the time of writing, plans are being made to implement ULTMAT 2.1 in the Cooperative Research Ships (CRS) STRUC software. The main function of this software is to develop sea load cases for application to finite element structural models. Incorporation of ULTMAT 2.1 will allow hull girder loads to be compared directly to ultimate strength results within the STRUC software.

Smith, M. J. (2006). ULTMAT 2.1 User’s Manual. DRDC Atlantic TM 2006-049. Defence R&D Canada - Atlantic.

Sommaire

Introduction

ULTMAT 2.1 est un programme informatique qui a été développé à RDDC Atlantique afin de calculer la résistance définitive de la poutre-coque des navires. La version 2.1 constitue une refonte importante du code avec l'ajout de capacités d'analyse plus étendues que dans les versions antérieures. Elle a été mise en œuvre dans l'outil logiciel de GAMSN (IST) afin de permettre d'évaluer rapidement tout dommage lié à la résistance de la classe Halifax. Elle peut aussi servir en mode autonome.

Résultats

À l'aide de l'information fournie dans le présent document, un utilisateur d'ULTMAT 2.1 pourra calculer la résistance définitive de la poutre-coque des navires, peu importe l'orientation de la résistance, et obtenir les résultats sous la forme d'une limite ou d'une enveloppe de résistance (courbe d'interaction) ou encore d'un rapport entre le moment de la résistance et la courbure. Des spécifications liées au formatage et des données d'échantillonnage sont fournies pour tous les fichiers de saisie nécessaires. De même, les instructions d'installation et d'exécution du programme sont présentées. Des données d'échantillonnage en sortie sont aussi offertes pour plusieurs types d'analyse de la résistance définitive.

Pertinence

Pour pouvoir exploiter en toute sécurité un navire, on doit s'assurer que la poutre-coque peut résister de manière satisfaisante à des charges de mer maximales, voire extrêmes. Cette résistance ou cette capacité peut se détériorer avec le temps du fait de la corrosion et d'autres types de dommages. Comme il peut s'avérer nécessaire d'utiliser pendant de courtes périodes un navire présentant des dommages importants, p. ex. jusqu'à ce qu'on puisse atteindre un port de sûreté afin de le réparer, il est essentiel de disposer d'une capacité de prédiction précise des dommages portés à la poutre-coque, et ce dans le but de maintenir une marge sécuritaire adéquate. Aussi, un navire endommagé ou inondé en partie peut ne pas offrir de charges en flexion dans l'orientation verticale prédominante. En pareil cas, une capacité de prédiction de la résistance bi-axiale (résistance verticale et horizontale combinée) est essentielle.

Plans futurs

Au moment d'écrire ces lignes, des plans sont en cours afin de mettre en place l'ULTMAT 2.1 dans le logiciel Cooperative Research Ships (CRS) STRUC. La fonction principale de ce logiciel est de concevoir des cases de charges de mer afin de les appliquer à des modèles structuraux d'éléments définis. L'intégration d'ULTMAT 2.1 permettra de comparer directement les charges de la poutre-coque avec les résultats définitifs relatifs à la résistance dans le logiciel STRUC.

Smith, M. J. (2006). ULTMAT 2.1 User's Manual. RDDC Atlantique TM 2006-049. Recherche et développement pour la défense Canada – Atlantique.

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1. Introduction

ULTMAT 2.1 is computer program for calculating ultimate hull girder strength of longitudinally stiffened, transversely framed ships. The original ULTMAT code was developed at DREA in the mid 1980s [1]. It provided the capability for calculating the ultimate bending moment strengths in hog and sag. The method made use of effective strength and limit state equations for stiffened panels and an equilibrium technique for finding the maximum bending moments. Later versions of the code adopted some of the concepts of the progressive collapse method first developed by Smith [2] for the NS94 codes, and were able to determine the moment-curvature relationship in hog and sag. Still other versions were developed to calculate interaction curves describing a two-dimensional envelope of ultimate bi-axial bending moments at a given cross section.

Beginning in 2000, the ULTMAT code was completely redeveloped so as to provide it with full bi-axial strength and moment-curvature prediction capabilities [3]. The redeveloped code was briefly known as RESULTS (Residual and Ultimate Strength), and was later renamed as ULTMAT 2.1. It is based on the progressive failure method, in which independently acting structural units comprise the ship hull girder, and where the elasto-plastic compression and collapse behaviour of individual units is provided by load-shortening curves. In addition to elasto-plastic analysis, the program can evaluate the bi-axial first-yield and fully developed plastic bending moment characteristics of a cross section.

ULTMAT 2.1 was designed to operate in either standalone mode or within the ultimate strength interface software ULTSAS, which was developed by Martec Limited under contract to DREA and DERA (UK) [4-6]. It was later incorporated into the ISSMM (Improved Ship Structure Maintenance Management) Software Tool (IST) for damaged strength assessments of the Halifax class. At the time of writing, plans are being made to incorporate ULTMAT 2.1 into the Cooperative Research Ships (CRS) STRUC software [7-8], which will allow bending loads calculated with STRUC to be compared directly with hull girder strength predictions.

The present document provides a more complete and updated version of the ULTMAT 2.1 user's manual, and replaces a previous version provided in an annex to Ref [3]. The manual is organized as follows. Section 2 provides instructions on how to install the ULTMAT 2.1 program and databases. Section 3 gives an overview of the steps required to run the program in standalone mode. The remainder of the manual describes the preparation of input data files: Section 4 defines the format for the master data file, and Sections 5, 6, and 7 give the format for input files defining the ship cross section, structural materials, and additional load shortening curves, respectively. Finally, Section 8 provides examples of all input data files and sample output results for several analysis types.

1.1 A word about notation

Throughout this manual, `courier font` is used to denote user-supplied input. A `regular typeface` in this font indicates input that is to be supplied verbatim; *`italics`* are used for the names of input variables, and indicate that integer, floating point, or character string input is required from the user.

2. Installing ULTMAT 2.1

The ULTMAT 2.1 program is comprised of the following components:

1. A Windows (2000/XP) executable file Ultmat.exe;
2. Ultmat.paths text file;
3. Load-shortening curve databases.

Ultmat.exe and Ultmat.paths are in the Program.zip archive, and should be uncompressed and copied to a convenient location on the hard disk, e.g. \Ultmat\Program\…. This is the default execution directory.

The load-shortening curve databases are provided in an archive LSC.zip. This archive should be uncompressed in a location on the hard disk where it will not be easily overwritten or erased. For example: \Ultmat\Database\…. Ensure that the internal folder structure is preserved when the archive is unpacked. When this is completed, the load-shortening curve databases should be found in a subfolder called "LSC DBs".

The location of the load shortening curve databases is communicated to ULTMAT through the Ultmat.paths file. This file contains the following keystring and path name string:

```
LSDataBase          LS_database_path_name
```

where *LS_database_path_name* defines the full path location of the "LSC DBs" subfolder. See Section 8.1.1 for an example. The internal structure of the "LSC DBs" subfolder should not be altered, as this will disrupt ULTMAT's ability to access the database.

3. Running ULTMAT 2.1

The following four steps should be carried out before running ULTMAT:

1. Ensure that the program has been installed, and that the location of the load-shortening curve databases folder “LSC DBs” is correctly defined in the Ultmat.paths file.

2. Create a text file called Ultmat.inp in the default execution directory. On the first record of this file, enter the string identifier `jobname`. This string should contain the path and prefix name of the master data file to be executed by ULTMAT. See Section 8.1.2 for an example Ultmat.inp file.

3. Create a master data file called `jobname.`usx that specifies the type of ultimate strength analysis, the load-shortening curve database, and the locations of key files. The master data file is described in detail in Section 4.

4. Create the cross section data file and the materials data file. If necessary, also create a file containing additional load-shortening curves. These files are described in detail in Sections 5, 6, and 7, respectively.

ULTMAT 2.1 can now be executed. Examples of the various input data files used by ULTMAT are provided in Section 8.1. Sample results for several analysis types can be found in Section 8.2.

4. Master data file

The master data file *jobname*.usx contains information about the type of ultimate strength analysis to be performed, as well as the names, locations and formats of the input and output data files. A *jobname*.usx file must be provided for every ULTMAT analysis. Formatting of the *jobname*.usx file is described below, and an example *jobname*.usx file is provided in Section 8.1.3.

4.1 Analysis types

An `Execute` group definition is used to define the type of ultimate strength analysis to be performed. Various options available for `Execute` are described in the following subsections.

4.1.1 Bi-axial moment-curvature analysis

Performs a moment-curvature analysis in a user-defined direction of bending.

```
Execute BiaxialMC {
   Direction  phi
   StepSize   curvatureStepSize
   Steps      numSteps
}
```

where

phi	angle ϕ (in degrees) of the neutral axis of bending, measured counter-clockwise from the positive lateral axis (float). See Figure 1.
curvatureStepSize	scalar curvature increment size, expressed as a fraction of the first-yield curvature in the defined direction (float, defaults to 0.005)
numSteps	number of curvature steps to be taken (int, defaults to 1000)

4.1.2 Hog and sag moment-curvature analysis

Performs the two vertical bending moment-curvature analyses.

```
Execute HogAndSagMC {
   StepSize  curvatureStepSize
   Steps     numSteps
}
```

where

curvatureStepSize	scalar curvature increment size, expressed as a fraction of the first-yield hull curvature in the defined direction (float, defaults to 0.005)
numSteps	number of curvature steps to be taken (int, defaults to 1000)

Sample ULTMAT output for a hog and sag moment-curvature analysis is provided in Section 8.2.1.

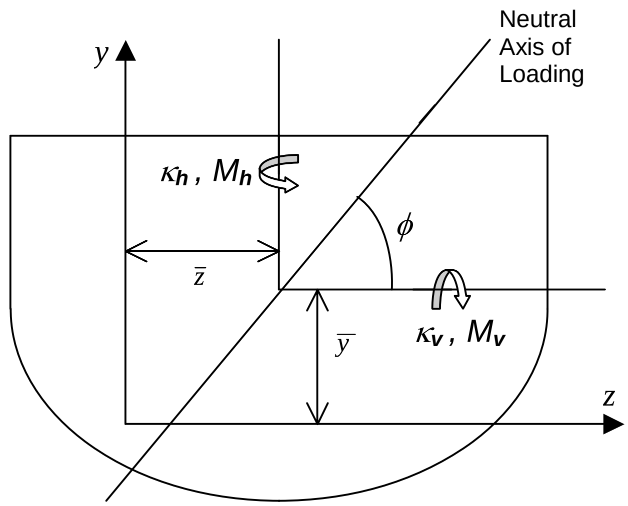

Figure 1: Bi-axial bending of a ship hull girder.

4.1.3 Bi-axial static strength analysis

Finds the ultimate bending capacity in a user-defined direction.

```
Execute BiaxialStrength {
   Direction  phi
   StepSize   momentStepSize
}
```

where

phi	angle ϕ (in degrees) of the neutral axis of bending, measured counter-clockwise from the positive lateral axis (float). See Figure 1.
momentStepSize	scalar moment increment size, expressed as a fraction of the first-yield bending moment in the defined direction (float, defaults to 0.005).

4.1.4 Interaction curve analysis

Performs a series bi-axial strength analyses to create an envelope of maximum bending moments.

```
Execute InteractionCurve {
   Points      numPoints
   StepSize    momentStepSize
}
```

where

numPoints	number of points in the interaction curve (int). For each bending direction, one point on the interaction curve is calculated. The *numPoints* bending directions are evenly distributed over 360 degrees.
momentStepSize	scalar moment increment size, expressed as a fraction of the first-yield bending moment (float, defaults to 0.005).

Sample ULTMAT output for an interaction curve analysis is provided in Section 8.2.2.

4.1.5 First-yield bending moment analysis

Finds the bending moment that produces a first-yield condition in a structural unit, ignoring the buckling behaviour of structural units in compression.

```
Execute YieldMoment {
   Direction  phi
}
```

where *phi* is the angle ϕ (in degrees) of the neutral axis of bending, measured counter-clockwise from the positive lateral axis (float). See Figure 1. Sample ULTMAT output for a first-yield bending moment analysis is provided in Section 8.2.3.

4.1.6 Plastic bending moment analysis

Finds the fully developed plastic bending moment in a user-defined direction.

```
Execute PlasticMoment {
   Direction  phi
}
```

where *phi* is the angle ϕ (in degrees) of the neutral axis of bending, measured counter-clockwise from the positive lateral axis (float). See Figure 1. Sample ULTMAT output for a plastic bending moment analysis is provided in Section 8.2.4.

4.2 Cross section data file

A `XSectionData` group definition is used to define the cross-section data file to be accessed by ULTMAT:

```
XSectionData  {
    format  formatType
    file    fileName
}
```

where

formatType	string identifier for the cross-section format. Allowable identifiers are `generic` and `hood` (string).
fileName	name of the cross section data file, path included (string).

4.3 Materials data file

A `MaterialsData` command is used to define the materials data file to be accessed by ULTMAT:

```
MaterialsData fileName
```

where *`fileName`* is the name of the file (including path) containing the structural materials data (string).

4.4 Beam section database file

A `BeamData` command is used to define the location and name of the HOOD beam database file to be accessed by ULTMAT:

```
BeamData fileName
```

where *`fileName`* is the name of the HOOD beam database file, path included (string). This command is only required when using a cross section in HOOD format.

4.5 Load shortening curve data

Load shortening (L-S) curve databases and files containing additional L-S curves are specified with a `LSCurveData` group definition.

```
LSCurveData {
    dataBase      dataBaseName
    file          fileName
}
```

where

`dataBaseName`	name of the L-S curve database from which stress-strain behaviour of individual structural units is interpolated. Three L-S curve databases are available to the user: `EndToEndCPF`, and `CentreToCentreCPF` (string). `EndToEndCPF` is recommended for most warship structures.
`fileName`	name of the file (including path) containing additional L-S curve definitions (string).

4.6 Results and error files

ULTMAT results are written to a file specified by the `ResultsFile` command.

```
ResultsFile   fileName
```

where *`fileName`* is the name of the file, path included (string). In addition, the program will create a file *`jobname`*`.err` for output of error or warning messages.

5. Cross section data file

The cross section data file defines the longitudinal structure of a ship at a particular cross section. The longitudinal structure between two adjacent frames is input as a collection of small, independently acting units. Three types of structural units can used to make up the cross section, as shown in Figure 2: longitudinal stiffened panels, transversely stiffened panels, and hard corners.

Longitudinal stiffened panels are comprised of two adjacent plates and a single longitudinal stiffener. Transversely stiffened panel units are comprised of plating stiffened with one or more transverse beams; these units can also be used to represent unstiffened plating. A hard corner unit is used to represent parts of the structure that do not buckle in compression, e.g., the plating immediately adjacent to the junction of a deck and side shell. Elastic perfectly plastic behaviour is assumed for both tension and compression of hard corners, and therefore they do not make use of load-shortening curves.

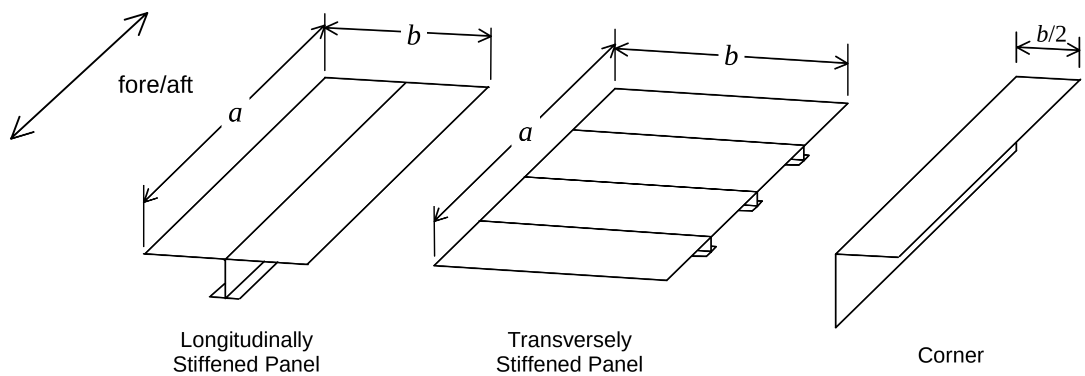

Figure 2: Structural units for defining the longitudinal structure between two adjacent frames.

5.1 Structural unit properties

The following parameters are used to define the properties of longitudinal stiffened panel units.

The plate slenderness parameter is defined as

$$\beta = (b / t)\sqrt{\sigma_y / E}$$

where b is the width of plating, t is the plate thickness, σ_y is the plating yield stress, and E is the elastic modulus.

The column slenderness parameter is defined as

$$\lambda = (a / \pi r)\sqrt{\sigma_y / E}$$

where a is the overall length (i.e., the interframe distance), and r is a radius of gyration of the plate-stiffener combination given by,

$$r = \sqrt{I_e' / A_e}$$

Area $A_e = b_e t$, where b_e is an effective width of plating determined by,

$$b_e / b = 1/\beta - 1/\beta^2 , \qquad \beta > 1$$
$$= 1 , \qquad \beta \leq 1$$

Second moment of area I'_e is determined using a reduced effective width b'_e for the plating given by

$$b_e / b = 1/\beta , \qquad \beta > 1$$
$$= 1 , \qquad \beta \leq 1$$

The area ratio A_s/A is the ratio of a stiffener cross sectional area, A_s, to the total cross sectional area of the panel as seen in the transverse plane:

$$A_s/A = A_s/(A_s + b\, t)$$

Background theory and further detail can be found in Refs. [3,9].

The Halifax class L-S curve databases provide curves for various combinations of β, λ and A_s/A. The parameters values represented in the databases are given in Table 1. Database curves are also provided for the three levels of plating imperfection δ_p, listed in Table 1 as a ratio of $\beta^2 t$. Stiffener imperfection (δ_s) and plating residual stress (σ_r) are included in the database curves at a single level each.

Table 1: Range of Parameters Represented in Halifax Class LSC Databases

Plate slenderness (β)	1.0, 2.0, 3.0, 4.0
Column slenderness (λ)	0.3, 0.6, 0.9, 1.2
Area ratio (A_s/A)	0.2, 0.275, 0.35
Max plating imperfection ($\delta_p/\beta^2 t$)	0.1, 0.2, 0.3
Max stiffener imperfection (δ_s / a)	0.001
Plating residual stress (σ_r/σ_y)	0.15

5.2 Generic format

See Section 8.1.4 for an example of a cross sectional data in generic format. The first line of the file must have the following statement:

```
#Units numUnits
```

where *numUnits* is the total number of structural units in the cross section (int).

The remainder of the file lists the definitions of the individual units in any order. A structural unit is defined with a group definition of the following form:

```
UnitTypeName {
    material        matName
    position        zPos  yPos
    effectiveness   effValue
    area            xSectionArea
    LSCurve         curveName
    ... etc.
}
```

where

UnitTypeName	identifies the structural unit type (string). Three string identifiers may be used for *UnitTypeName*: `LongStiffPanel` for longitudinally stiffened panels. `TranStiffPanel` for transversely stiffened panels. `HardCorner` for hard corner units.
matName	name of the unit material (string).
yPos	vertical position of the unit centroid (float).
zPos	horizontal position of the unit centroid (float).
effValue	effectiveness of the unit (0.0 ≤ *effValue* ≤ 1.0) (float).
xSectionArea	cross sectional area of the unit in the transverse plane (float).
curveName	name of a specific load-shortening curve to be used with this panel (string). The `LSCurve` statement is optional. If it is omitted, the load-shortening properties of the unit will be interpolated from the database.

N.B. `material`, `position`, and `area` statements are required for all structural unit types. Additional input needed for the various structural unit types is given below.

5.2.1 Longitudinal Stiffened Panels

Four additional statements are needed within the `LongStiffPanel` group definition.

```
plateSlender    betaValue
columnSlender   lambdaValue
areaRatio       arValue
imperfection    imperfLevel
```

where

betaValue	plate slenderness (β) for the panel (float).
lambdaValue	column slenderness value (λ) for the panel (float).
arValue	stiffener-area to total-area ratio (A_s/A) for the panel (float).
imperfLevel	string identifier defining the level of plating imperfection (geometric and residual stresses) in the panel (string). Allowable strings are `SLIGHT`, `AVERAGE` and `SEVERE`, which correspond to the three plating imperfection levels listed in Table 1.

5.2.2 Transversely Stiffened Panels

Four additional statements are needed within the `TranStiffPanel` group definition.

```
plateSlender     betaValue
aspectRatio      alphaValue
```

where

betaValue	plate slenderness (β) for the panel (float).
alphaValue	panel aspect ratio (a/b) (float).

5.2.3 Hard Corner Units

No additional information is needed for these units.

5.3 HOOD format

This format is identical to the HOOD cross-sectional file format (*.hod) used by the ULTSAS program [4-6]. It defines structural units in terms of individual beams and plates, rather than the user-supplied parameters used in the generic format. When using the HOOD format, these parameters (plate slenderness, column slenderness, and area ratio) are calculated by ULTMAT at run time.

The HOOD format is more limited than the generic format in that it is not possible to assign a user-supplied LS-curve to a structural unit in place of interpolation from the LSC database. Another limitation of the HOOD format is that it does not allow the imperfection level of longitudinally stiffened panels to be specified by the user. Instead, a default `AVERAGE` level of imperfection is assumed. For these reasons, the HOOD format is not recommended for general use. It has been provided mainly for the convenience of ULTSAS users, who may possess a large number of legacy cross-section models in this format.

Input is key string driven, where possible key strings are `KeyPoints`, `Plates`, `Stiffeners`, `LSPs`, `TSPs`, `HCs`. Following each key string are the definitions of structural entities of each type. The list of entities is initiated with a single open bracket "`[`" and a terminated with a single closing bracket "`]`". Entities are separate by commas.

5.3.1 Keypoints

The `KeyPoints` key string is used to define a set of keypoints:

```
KeyPoints   [
```

```
        kpIndex    hCoord    vCoord ,
        …
]
```

where

kpIndex	index identifier for a key point (int)
hCoord	the horizontal (z) coordinate (float)
vCoord	the vertical (y) coordinate (float)

5.3.2 Plates

The `Plates` key string is used to define a set of plates:

```
Plates      [
        pIndex     kp1    kp2    tk    a    matName     "idString",
        …
]
```

where

pIndex	index identifier for a plate (int)
kp1 kp2	key point indices defining the two endpoints in the transverse plane (int, int)
tk	thickness (float)
a	plate length in longitudinal direction (float)
matName	string identifier defining the material in the HOOD material database (string)
idString	string identifier for the plate (not used by ULTMAT) (string)

5.3.3 Beams

The `Stiffeners` keystring is used to define a set of beams:

```
Stiffeners  [
        sIndex   kp1  hDir   vDir  a   sectName  matName  "idString",
        …
]
```

where

sIndex	index identifier for a beam (int)
kp1	keypoint index defining the location of the centroid (int)
hDir vDir	horizontal and vertical direction cosines defining the beam orientation (float, float)
a	beam length in longitudinal direction (float)
sectName	string identifying a beam section in the HOOD beam database (string)
matName	string identifying a material type in the HOOD material database (string)
idString	string identifier for the beam (not used by ULTMAT) (string)

5.3.4 Longitudinally Stiffened Panels

The `LSPs` keystring is used to define a set of longitudinally stiffened panels:

```
LSPs   [
       index   bInd   pInd1   pInd2   "idString"  effValue,
       …
]
```

where

index	index identifier for the unit (int)
bInd	index of the beam stiffener (int)
pInd1 pInd2	indices of the two plates attached to the beam (int, int)
idString	string identifier for the unit (not used by ULTMAT) (string)
effValue	panel effectiveness value (0.0 ≤ *effValue* ≤ 1.0) (float)

5.3.5 Transversely Stiffened Panels

The `TSPs` keystring is used to define a set of transversely stiffened panels:

```
TSPs   [
       index  bInd   pInd1   pInd2   "idString"  effValue,
]
```

where

index	index identifier for the unit (int)
pInd1 pInd2	indices of two adjacent plates that comprise the transverse stiffened panel (int, int).
idString	string identifier for the unit (not used by ULTMAT) (string)
effValue	panel effectiveness value (0.0 ≤ *effValue* ≤ 1.0) (float)

5.3.6 Hard Corners

The `HCs` keystring is used to define a set of hard corners:

```
HCs    [
       index  [ p1   p2 …]  [ b1   b2 … ]  "idString"  effValue,
       …
]
```

where

index	index identifier for the panel unit (int)
p1 p2 …	indices of constituent plates (int, int …)
b1 b2 …	indices of constituent beams (int, int …)
idString	string identifier for the unit (not used by ULTMAT) (string)
effValue	panel effectiveness value (0.0 ≤ *effValue* ≤ 1.0) (float)

6. Materials file format

The material properties of the structural units must be defined in a separate materials data file for all ULTMAT analyses. The file lists the definitions of the individual materials in any order. A material is defined with a group definition of the following form:

```
Material  {
   name            matName
   modulus         E
   yieldStress     sigmaY
   yieldStrain     epsilonY
}
```

where

matName	unique identifier for the material (string).
E	elastic modulus of the material (float).
sigmaY	yield stress value (float).
epsilonY	yield strain (float).

The `name` and `modulus` statements must be supplied for all materials. At least one of either the `yieldStress` or the `yieldStrain` statements must also be provided. For an example materials data file, see Section 8.1.5.

7. Additional load shortening curves

If load-shortening curves in addition to those in the L-S databases are to be used in an analysis, it is strongly recommended that they be included in a separate file, rather than attempting to accomplish the same thing by expansion or alteration of the database curves. The name of the file is defined in `LSCurveData` group definition provided in the master data file.

L-S curves are identified by a unique string identifier and can be listed in any order. A L-S curve is defined using a `LSCurve` group:

```
LSCurve {
   name  identifier
   curve {
      strain_i   stress_i
      ...
   }
}
```

where

identifier	unique identifier for the curve (string).
strain_i, stress_i	the strain (normalized to the yield strain), and the stress (normalized to yield stress) of a vertex on the load-shortening curve (float, float).

Note that *strain_i, stress_i* values should be supplied for each point on the curve (minimum of two points), and that these should all appear between the opening and closing braces of the `curve` group. For an example load-shortening curve data file, see Section 8.1.6.

8. Examples

8.1 ULTMAT Input files

8.1.1 Example Ultmat.paths file

The following input line defines the “LSC DBs” database subfolder is to be found in the \Ultmat\Version21\Database folder:

```
LSDataBase         \Ultmat\Version21\Database
```

8.1.2 Example Ultmat.inp file

The following input line defines *jobname* to be `CollisionCase` with input data files located in the \Ultmat\Version21\Examples folder.

```
\Ultmat\Version21\Examples\CollisionCase
```

8.1.3 Example master data file

```
Execute InteractionCurve {
       Points      36
       StepSize    .005
}

XSectionData  {
    format  generic
    file    \Ultmat\Models\amidShips.xsm
}

MaterialsData \Ultmat\Models\cpf.mat

LSCurveData    {
    dataBase  EndToEndCPF
    file      extraCurves.lsc
}

ResultsFile    \Ultmat\Models\amidShips.results
```

8.1.4 Example cross-section data – generic format

```
#Units
LongStiffPanel {
       material             mat0
       position             -5500 11270.2
       area                 10317.3
       plateSlender         2.399
       columnSlender        0.42
```

```
        areaRatio            0.275
        imperfection         AVERAGE
}
LongStiffPanel {
        material             mat0
        position             5500 11270.2
        area                 10317.3
        plateSlender         2.399
        columnSlender        0.42
        areaRatio            0.275
        imperfection         AVERAGE
}
LongStiffPanel {
        material             mat1
        position             -3300 6200
        area                 6109.83
        plateSlender         4.425
        columnSlender        0.246
        areaRatio            0.275
        imperfection         AVERAGE
}
HardCorner {
        material             mat1
        position             -8198.07 11105.3
        area                 4662.17
}
HardCorner {
        material             mat1
        position             8198.07 11105.3
        area                 4662.18
}
…
```

8.1.5 Example materials data file

```
Material  {
        name        mat0
        modulus     210000
        yieldStress 700
}
Material  {
        name        mat1
        modulus     210000
        yieldStress 350
        yieldStrain 0.00166667
}
```

8.1.6 Example load-shortening curve data file

```
LSCurve {
    name  damagedPanel
    curve {
        0         0
        0.8       0.45
        5.93908 -0.12
    }
```

```
}
LSCurve {
    name extraCurve
    curve {
       0        0
       0.7      0.56
       2.04031  0.2
       2.10122  0.15
       5.93908 -0.2
    }
}
LSCurve {
    name  anotherCurve
    curve {
        0           0
        0.03        0.0295037
        0.39551     0.385691
        0.456429    0.443204
        0.517347    0.471501
        0.578265    0.472144
        0.639184    0.471789
        0.700102    0.397976
        0.76102     0.320995
        0.821939    0.293424
        0.882857    0.274805
        0.943776    0.260477
        1.00469     0.248942
        1.06561     0.239195
        1.12653     0.230824
        1.18745     0.223483
        1.24837     0.217009
        1.3702      0.205859
        1.43112     0.201045
        1.61388     0.188802
        1.6748      0.185304
        2.10122     0.16606
        2.16214     0.163849
        3.44143     0.133566
        3.50235     0.132577
        5.93908     0.106748
    }
}
```

8.2 Output files

8.2.1 Example results: Hog and Sag analysis

```
 Sag Analysis
==============
                   Biaxial Moment curvature results
                   --------------------------------
   Horiz Curv     Vert Curv     Total Curv  Horiz Moment   Vert Moment  Total Moment

  0.00000e+000  2.39692e-008  2.39692e-008 -3.07827e+006  6.92862e+010  6.92862e+010
  0.00000e+000  4.79383e-008  4.79383e-008 -6.09861e+006  1.38298e+011  1.38298e+011
  0.00000e+000  7.19075e-008  7.19075e-008 -9.22585e+006  2.06391e+011  2.06391e+011
  0.00000e+000  9.58766e-008  9.58766e-008 -1.26478e+007  2.73672e+011  2.73672e+011
  0.00000e+000  1.19846e-007  1.19846e-007 -2.53870e+007  3.38754e+011  3.38754e+011
```

```
  0.00000e+000  1.43815e-007  1.43815e-007 -4.78733e+007  4.00636e+011  4.00636e+011
  0.00000e+000  1.67784e-007  1.67784e-007 -8.25123e+007  4.51178e+011  4.51178e+011
  0.00000e+000  1.91753e-007  1.91753e-007 -1.31268e+008  4.80643e+011  4.80643e+011
  0.00000e+000  2.15722e-007  2.15722e-007 -1.89650e+008  4.96171e+011  4.96171e+011
  0.00000e+000  2.39692e-007  2.39692e-007 -2.54892e+008  5.00419e+011  5.00419e+011
  0.00000e+000  2.63661e-007  2.63661e-007 -3.23848e+008  5.00449e+011  5.00449e+011
  0.00000e+000  2.87630e-007  2.87630e-007 -4.00380e+008  4.98866e+011  4.98866e+011
  0.00000e+000  3.11599e-007  3.11599e-007 -4.85901e+008  4.92678e+011  4.92678e+011
  0.00000e+000  3.35568e-007  3.35568e-007 -5.67628e+008  4.85321e+011  4.85321e+011
  0.00000e+000  3.59537e-007  3.59537e-007 -6.24922e+008  4.78359e+011  4.78360e+011


 Hog Analysis
==============
                   Biaxial Moment curvature results
                   --------------------------------
   Horiz Curv     Vert Curv     Total Curv  Horiz Moment   Vert Moment  Total Moment

  0.00000e+000 -3.96089e-008  3.96089e-008  4.81929e+007 -1.26758e+011  1.26758e+011
  0.00000e+000 -7.92178e-008  7.92178e-008  9.65587e+007 -2.53705e+011  2.53705e+011
  0.00000e+000 -1.18827e-007  1.18827e-007  1.45181e+008 -3.80914e+011  3.80914e+011
  0.00000e+000 -1.58436e-007  1.58436e-007  1.93771e+008 -5.08083e+011  5.08083e+011
  0.00000e+000 -1.98045e-007  1.98045e-007  2.42257e+008 -6.35138e+011  6.35138e+011
  0.00000e+000 -2.37654e-007  2.37654e-007  2.90609e+008 -7.61687e+011  7.61687e+011
  0.00000e+000 -2.77262e-007  2.77262e-007  3.62976e+008 -8.42111e+011  8.42111e+011
  0.00000e+000 -3.16871e-007  3.16871e-007  4.42524e+008 -9.10302e+011  9.10302e+011
  0.00000e+000 -3.56480e-007  3.56480e-007  5.21495e+008 -9.67064e+011  9.67065e+011
  0.00000e+000 -3.96089e-007  3.96089e-007  6.15411e+008 -9.96797e+011  9.96798e+011
  0.00000e+000 -4.35698e-007  4.35698e-007  7.09808e+008 -1.01840e+012  1.01840e+012
  0.00000e+000 -4.75307e-007  4.75307e-007  7.97383e+008 -1.03578e+012  1.03578e+012
  0.00000e+000 -5.14916e-007  5.14916e-007  8.71654e+008 -1.04799e+012  1.04799e+012
  0.00000e+000 -5.54525e-007  5.54525e-007  9.18426e+008 -1.05288e+012  1.05288e+012
  0.00000e+000 -5.94134e-007  5.94134e-007  9.45977e+008 -1.05300e+012  1.05300e+012
```

8.2.2 Example results: Interaction curve analysis

```
Interaction Curve
-----------------
  Horz Moment   Vert Moment

 -3.72084e+007  5.14424e+011
  8.91052e+010  5.07635e+011
  1.74394e+011  4.86092e+011
  2.57770e+011  4.49495e+011
  3.42584e+011  4.01798e+011
  4.30446e+011  3.47035e+011
  5.05610e+011  2.88075e+011
  5.82722e+011  2.07361e+011
  6.64050e+011  1.09286e+011
  7.55528e+011 -1.37779e+010
  8.72149e+011 -1.68340e+011
  9.52722e+011 -3.47534e+011
  8.56183e+011 -4.95163e+011
  7.36705e+011 -6.26593e+011
  6.10747e+011 -7.45188e+011
  4.73781e+011 -8.56719e+011
  3.30566e+011 -9.51466e+011
  1.71964e+011 -1.01896e+012
  4.18264e+007 -1.04474e+012
 -1.71777e+011 -1.01834e+012
 -3.30234e+011 -9.50384e+011
 -4.73531e+011 -8.55433e+011
 -6.10243e+011 -7.44232e+011
 -7.35537e+011 -6.25925e+011
 -8.54992e+011 -4.94841e+011
 -9.52446e+011 -3.47002e+011
 -8.74200e+011 -1.68068e+011
```

```
 -7.57332e+011 -1.39454e+010
 -6.65445e+011  1.09851e+011
 -5.84129e+011  2.07320e+011
 -5.06780e+011  2.88648e+011
 -4.30458e+011  3.48111e+011
 -3.42500e+011  4.03399e+011
 -2.59807e+011  4.49583e+011
 -1.74718e+011  4.86900e+011
 -9.01748e+010  5.07812e+011
 -3.72084e+007  5.14424e+011
```

8.2.3 Example results: First yield analysis

```
Biaxial First Yield Moment
--------------------------
Direction of Bending    = 3.000000e+001 degrees
Horizontal Yield Moment = 4.118640e+011
Vertical Yield Moment   = 7.133694e+011
Total Yield Moment      = 8.237280e+011
Net Curvature at Yield  = 2.292233e-007
```

8.2.4 Example results: Plastic moment analysis

```
Biaxial Plastic Moment
----------------------
Direction of Bending      = 1.800000e+002 degrees
Horizontal Plastic Moment = 1.671830e-004
Vertical Plastic Moment   = -1.123832e+012
Total Plastic Moment      = 1.123832e+012
```

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