ANEXOS

MODELADO Y SIMULACIÓN EN 3D DE UN CATÉTER FLEXIBLE ORIENTABLE A TRAVÉS DE JOYSTICK

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Ingeniería en Automática Industrial

Popayán, abril 2015

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Tesis presentada a la Facultad de Ingeniería Electrónica y Telecomunicaciones de la Universidad del Cauca para la obtención del Título de

Ingeniero en Automática Industrial

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ANEXO A: CODIGO CALCULO NUMERICO MGI

El código principal (Matlab Function) asignado al bloque MGI del diagrama de bloques en Silmulink es mostrado a continuación:

```
function cateter_mgi(block)
  setup(block);
 end

function setup(block)

  %% Register number of input and output ports
  block.NumInputPorts                   = 2;
  block.NumOutputPorts                  = 2;

  %% Setup functional port properties to dynamically
  %% inherited.
  block.SetPreCompInpPortInfoToDynamic;
  block.SetPreCompOutPortInfoToDynamic;
  block.InputPort(1).DirectFeedthrough  = true;
  block.InputPort(1).Dimensions         = 6;
  block.InputPort(2).DirectFeedthrough  = true;
  block.InputPort(2).Dimensions         = 7;

  %% Output ports
  block.OutputPort(1).Dimensions        = 7;
  block.OutputPort(2).Dimensions        = 3;

  %% Set block sample time to inherited
  block.SampleTimes                     = [-1 0];

  %% Run accelerator on TLC
  block.SetAccelRunOnTLC(true);

  %% Register methods
  block.RegBlockMethod('Outputs',@Output);
  block.RegBlockMethod('SetInputPortSamplingMode',@SetInpPortFrameData);
end

function SetInpPortFrameData(block, idx, fd)
  block.InputPort(idx).SamplingMode = fd;
  block.OutputPort(1).SamplingMode  = fd;
  block.OutputPort(2).SamplingMode  = fd;
end

function Output(block)
% Joint position
Ref             = block.InputPort(1).Data;
Q               = block.InputPort(2).Data;

% Cartesian reference trajectory
X               = Ref(1:3);
XDot            = Ref(4:6);
```

```
% Error
T               = cateter_mgd(Q);
R               = T(1:3,1:3);
Error           = X - T(1:3,4);

% Joint velocities
J               = matriz_jacobiana(Q);
QDot            = pinv(R * J) * (XDot);

% Output
block.OutputPort(1).Data = QDot;
block.OutputPort(2).Data = Error;
end
```

En otra Matlab function se debe poner el siguiente código llamado matriz_jacobiana.

```
function [J]    = matriz_jacobiana(Q)
Zeros           = @(R,C) zeros(R,C);

% Joint velocities are the columns of an identity matrix
NJoints         = length(Q);
Matrix_Qv       = eye(NJoints);

% Memory allocation
J               = Zeros(3,NJoints);

% Columns of the Jacobian matrix
TT              = matriz_transformacion(Q);

% Type of joint
S               = Zeros(NJoints,1);
%S(5)            = 1;   era una prismatica en el transluminal
for Col = 1:NJoints,
    Qv          = Matrix_Qv(:,Col);
    JCol        = linear_velocity_computation(TT, S, Qv);
    J(:,Col)    = JCol;
end
end

% Linear velocity for the reference frame N
function [V]    = linear_velocity_computation(TT, S, Qv)
Zeros           = @(R,C) zeros(R,C);
J_a_J           = [0; 0; 1];
NJoints         = length(Qv);
Jm1_W_Jm1       = Zeros(3,1);
Jm1_V_Jm1       = Zeros(3,1);
for j = 1:NJoints,
    % Kinematic parameters (all joints are rotational)
    Sj          = S(j);

    % Transformation matrix from reference frame j to reference frame j-1
    BRow        = 4*(j-1)+1;
    Jm1_T_J     = TT(BRow:BRow+3,:);
```

```
    J_R_Jm1      = Jm1_T_J(1:3,1:3)';
    Jm1_P_J      = Jm1_T_J(1:3,4);

    % Linear and angular velocity for the joint j
    J_W_Jm1      = J_R_Jm1 * Jm1_W_Jm1;
    J_W_J        = J_W_Jm1 + (1-Sj)*Qv(j)*J_a_J;
    J_V_J          = J_R_Jm1 * (Jm1_V_Jm1 + cross(Jm1_W_Jm1,Jm1_P_J)) +
Sj*Qv(j)*J_a_J;

    % Updating
    Jm1_W_Jm1    = J_W_J;
    Jm1_V_Jm1    = J_V_J;
end
V                = J_V_J;
End
```

ANEXO B: MDD Y MDI

B1 MODELO DINAMICO DIRECTO

A continuación se muestra el modelo dinámico directo obtenido de la herramienta Symoro:

```
% (*****************************************)
% (** SYMORO+ : SYmbolic MOdelling of RObots **)
% (**=====================================**)
% (**      IRCCyN-ECN - 1, rue de la Noe     **)
% (**      B.P.92101                         **)
% (**      44321 Nantes cedex 3, FRANCE      **)
% (**      www.irccyn.ec-nantes.fr           **)
% (*****************************************)


%                     Name      of      file      :      D:\Archivos      de
Programa\Irccyn\Robots\Cateter\Cateterbase.ddm



%       Geometric parameters


% j     ant    mu     sigma gamma b      alpha d      theta r


% 1     0      1      0     0     0      0     0      t1    0

%                                         pi
% 2     1      1      0     0     0      --    0      t2    0
%                                         2
```

```
%                                          pi
% 3     2     1     0     0     0      --    D3    t3    0
%                                          2
%                                         -pi
% 4     3     1     0     0     0      ---   D4    t4    0
%                                          2
%                                          pi
% 5     4     1     0     0     0      --    D5    t5    0
%                                          2
%                                         -pi
% 6     5     1     0     0     0      ---   D6    t6    0
%                                          2
%                                          pi
% 7     6     1     0     0     0      --    D7    t7    0
%                                          2


%              Inertial parameters

% j      XX      XY      XZ      YY      YZ      ZZ      MX      MY      MZ      M
Ia

% 1      0       0       0       0       0       ZZ1R    0       0       0       0
0

% 2      XX2R    XY2R    XZ2R    0       YZ2R    ZZ2R    MX2R    MY2R    0       0
IA2

% 3      XX3R    XY3R    XZ3R    0       YZ3R    ZZ3R    MX3R    MY3R    0       0
IA3

% 4      XX4R    XY4R    XZ4R    0       YZ4R    ZZ4R    MX4R    MY4R    0       0
IA4

% 5      XX5R    XY5R    XZ5R    0       YZ5R    ZZ5R    MX5R    MY5R    0       0
IA5

% 6      XX6R    XY6R    XZ6R    0       YZ6R    ZZ6R    MX6R    MY6R    0       0
IA6

% 7      XX7R    XY7     XZ7     0       YZ7     ZZ7     MX7     MY7     0       0
IA7


%      External   forces,friction   parameters,   joint   velocities   and
accelerations

% j       FX      FY      FZ      CX      CY      CZ      FS      FV      QP
QDP

% 1       FX1     FY1     FZ1     CX1     CY1     CZ1     FS1     FV1     QP1
QDP1
```

```
% 2       FX2     FY2     FZ2     CX2     CY2     CZ2     FS2     FV2     QP2
QDP2

% 3       FX3     FY3     FZ3     CX3     CY3     CZ3     FS3     FV3     QP3
QDP3

% 4       FX4     FY4     FZ4     CX4     CY4     CZ4     FS4     FV4     QP4
QDP4

% 5       FX5     FY5     FZ5     CX5     CY5     CZ5     FS5     FV5     QP5
QDP5

% 6       FX6     FY6     FZ6     CX6     CY6     CZ6     FS6     FV6     QP6
QDP6

% 7       FX7     FY7     FZ7     CX7     CY7     CZ7     FS7     FV7     QP7
QDP7

% Base velocity, base accelerations, and gravity

% j     W0    WP0   V0    VP0   G

% 1     0     0     0     0     0

% 2     0     0     0     0     0

% 3     0     0     0     0     G3



%  Direct Calculation of the Joints Accelerations

% Equations:

% Declaration of the function
function Cateterbase_ddm()

% Declaration of global input variables
global t2 pi t3 t4 t5 t6 t7 QP1 QP2 QP3
global D3 QP4 D4 QP5 D5 QP6 D6 QP7 D7 XX2R
global XY2R XZ2R YZ2R ZZ2R XX3R XY3R XZ3R YZ3R ZZ3R MX3R
global MY3R XX4R XY4R XZ4R YZ4R ZZ4R MX4R MY4R XX5R XY5R
global XZ5R YZ5R ZZ5R MX5R MY5R XX6R XY6R XZ6R YZ6R ZZ6R
global MX6R MY6R XX7R XY7 XZ7 YZ7 ZZ7 MX7 MY7 IA7
global CZ7 GAM7 FV7 FS7 CX7 CY7 FX7 FY7 FZ7 CX6
global CY6 CZ6 FX6 FY6 FZ6 IA6 GAM6 FV6 FS6 CX5
global CY5 CZ5 FX5 FY5 FZ5 IA5 GAM5 FV5 FS5 CX4
global CY4 CZ4 FX4 FY4 FZ4 IA4 GAM4 FV4 FS4 CX3
global CY3 CZ3 FX3 FY3 FZ3 IA3 GAM3 FV3 FS3 MY2R
global MX2R CX2 CY2 CZ2 IA2 GAM2 FV2 FS2 ZZ1R CZ1
global GAM1 FV1 FS1 G3

% Declaration of global output variables
global QDP1 QDP2 QDP3 QDP4 QDP5 QDP6 QDP7
```

```
% Function description:

    S2=sin(t2);
    C2=cos(t2);
    Sa2=sin(pi./2.);
    Ca2=cos(pi./2.);
    S3=sin(t3);
    C3=cos(t3);
    Sa3=sin(pi./2.);
    Ca3=cos(pi./2.);
    S4=sin(t4);
    C4=cos(t4);
    Sa4=-sin(pi./2.);
    Ca4=cos(pi./2.);
    S5=sin(t5);
    C5=cos(t5);
    Sa5=sin(pi./2.);
    Ca5=cos(pi./2.);
    S6=sin(t6);
    C6=cos(t6);
    Sa6=-sin(pi./2.);
    Ca6=cos(pi./2.);
    S7=sin(t7);
    C7=cos(t7);
    Sa7=sin(pi./2.);
    Ca7=cos(pi./2.);
    A312=S2.*Sa2;
    A322=C2.*Sa2;
    WI12=A312.*QP1;
    WI22=A322.*QP1;
    WI32=Ca2.*QP1;
    W32=QP2 + WI32;
    A213=Ca3.*S3;
    A223=C3.*Ca3;
    A313=S3.*Sa3;
    A323=C3.*Sa3;
    WI13=A313.*W32 + C3.*WI12 + A213.*WI22;
    WI23=A323.*W32 - S3.*WI12 + A223.*WI22;
    WI33=Ca3.*W32 - Sa3.*WI22;
    W33=QP3 + WI33;
    JPR123=-(A313.*D3);
    JPR133=A213.*D3;
    JPR223=-(A323.*D3);
    JPR233=A223.*D3;
    JPR323=-(Ca3.*D3);
    JPR333=-(D3.*Sa3);
    A214=Ca4.*S4;
    A224=C4.*Ca4;
    A314=S4.*Sa4;
    A324=C4.*Sa4;
    WI14=A314.*W33 + C4.*WI13 + A214.*WI23;
    WI24=A324.*W33 - S4.*WI13 + A224.*WI23;
    WI34=Ca4.*W33 - Sa4.*WI23;
    W34=QP4 + WI34;
    JPR124=-(A314.*D4);
    JPR134=A214.*D4;
    JPR224=-(A324.*D4);
    JPR234=A224.*D4;
    JPR324=-(Ca4.*D4);
    JPR334=-(D4.*Sa4);
```

```
A215=Ca5.*S5;
A225=C5.*Ca5;
A315=S5.*Sa5;
A325=C5.*Sa5;
WI15=A315.*W34 + C5.*WI14 + A215.*WI24;
WI25=A325.*W34 - S5.*WI14 + A225.*WI24;
WI35=Ca5.*W34 - Sa5.*WI24;
W35=QP5 + WI35;
JPR125=-(A315.*D5);
JPR135=A215.*D5;
JPR225=-(A325.*D5);
JPR235=A225.*D5;
JPR325=-(Ca5.*D5);
JPR335=-(D5.*Sa5);
A216=Ca6.*S6;
A226=C6.*Ca6;
A316=S6.*Sa6;
A326=C6.*Sa6;
WI16=A316.*W35 + C6.*WI15 + A216.*WI25;
WI26=A326.*W35 - S6.*WI15 + A226.*WI25;
WI36=Ca6.*W35 - Sa6.*WI25;
W36=QP6 + WI36;
JPR126=-(A316.*D6);
JPR136=A216.*D6;
JPR226=-(A326.*D6);
JPR236=A226.*D6;
JPR326=-(Ca6.*D6);
JPR336=-(D6.*Sa6);
A217=Ca7.*S7;
A227=C7.*Ca7;
A317=S7.*Sa7;
A327=C7.*Sa7;
WI17=A317.*W36 + C7.*WI16 + A217.*WI26;
WI27=A327.*W36 - S7.*WI16 + A227.*WI26;
WI37=Ca7.*W36 - Sa7.*WI26;
W37=QP7 + WI37;
JPR127=-(A317.*D7);
JPR137=A217.*D7;
JPR227=-(A327.*D7);
JPR237=A227.*D7;
JPR327=-(Ca7.*D7);
JPR337=-(D7.*Sa7);
JW12=WI12.*XX2R + WI22.*XY2R + W32.*XZ2R;
JW22=WI12.*XY2R + W32.*YZ2R;
JW32=WI12.*XZ2R + WI22.*YZ2R + W32.*ZZ2R;
KW12=-(JW22.*W32) + JW32.*WI22;
KW22=JW12.*W32 - JW32.*WI12;
KW32=JW22.*WI12 - JW12.*WI22;
WQ12=QP2.*WI22;
WQ22=-(QP2.*WI12);
JW13=WI13.*XX3R + WI23.*XY3R + W33.*XZ3R;
JW23=WI13.*XY3R + W33.*YZ3R;
JW33=WI13.*XZ3R + WI23.*YZ3R + W33.*ZZ3R;
KW13=-(JW23.*W33) + JW33.*WI23;
KW23=JW13.*W33 - JW33.*WI13;
KW33=JW23.*WI13 - JW13.*WI23;
SW13=-(MX3R.*W33.^2) + WI23.*(MY3R.*WI13 - MX3R.*WI23);
SW23=-(MY3R.*W33.^2) - WI13.*(MY3R.*WI13 - MX3R.*WI23);
SW33=MX3R.*W33.*WI13 + MY3R.*W33.*WI23;
WQ13=QP3.*WI23;
```

```
    WQ23=-(QP3.*WI13);
    LW13=A313.*D3.*W32.*WI12 + A213.*D3.*WI12.*WI22 + C3.*(-(D3.*W32.^2)
- D3.*WI22.^2);
    LW23=A323.*D3.*W32.*WI12 + A223.*D3.*WI12.*WI22 - S3.*(-(D3.*W32.^2)
- D3.*WI22.^2);
    LW33=Ca3.*D3.*W32.*WI12 - D3.*Sa3.*WI12.*WI22;
    JW14=WI14.*XX4R + WI24.*XY4R + W34.*XZ4R;
    JW24=WI14.*XY4R + W34.*YZ4R;
    JW34=WI14.*XZ4R + WI24.*YZ4R + W34.*ZZ4R;
    KW14=-(JW24.*W34) + JW34.*WI24;
    KW24=JW14.*W34 - JW34.*WI14;
    KW34=JW24.*WI14 - JW14.*WI24;
    SW14=-(MX4R.*W34.^2) + WI24.*(MY4R.*WI14 - MX4R.*WI24);
    SW24=-(MY4R.*W34.^2) - WI14.*(MY4R.*WI14 - MX4R.*WI24);
    SW34=MX4R.*W34.*WI14 + MY4R.*W34.*WI24;
    WQ14=QP4.*WI24;
    WQ24=-(QP4.*WI14);
    LW14=A314.*D4.*W33.*WI13 + A214.*D4.*WI13.*WI23 + C4.*(-(D4.*W33.^2)
- D4.*WI23.^2);
    LW24=A324.*D4.*W33.*WI13 + A224.*D4.*WI13.*WI23 - S4.*(-(D4.*W33.^2)
- D4.*WI23.^2);
    LW34=Ca4.*D4.*W33.*WI13 - D4.*Sa4.*WI13.*WI23;
    JW15=WI15.*XX5R + WI25.*XY5R + W35.*XZ5R;
    JW25=WI15.*XY5R + W35.*YZ5R;
    JW35=WI15.*XZ5R + WI25.*YZ5R + W35.*ZZ5R;
    KW15=-(JW25.*W35) + JW35.*WI25;
    KW25=JW15.*W35 - JW35.*WI15;
    KW35=JW25.*WI15 - JW15.*WI25;
    SW15=-(MX5R.*W35.^2) + WI25.*(MY5R.*WI15 - MX5R.*WI25);
    SW25=-(MY5R.*W35.^2) - WI15.*(MY5R.*WI15 - MX5R.*WI25);
    SW35=MX5R.*W35.*WI15 + MY5R.*W35.*WI25;
    WQ15=QP5.*WI25;
    WQ25=-(QP5.*WI15);
    LW15=A315.*D5.*W34.*WI14 + A215.*D5.*WI14.*WI24 + C5.*(-(D5.*W34.^2)
- D5.*WI24.^2);
    LW25=A325.*D5.*W34.*WI14 + A225.*D5.*WI14.*WI24 - S5.*(-(D5.*W34.^2)
- D5.*WI24.^2);
    LW35=Ca5.*D5.*W34.*WI14 - D5.*Sa5.*WI14.*WI24;
    JW16=WI16.*XX6R + WI26.*XY6R + W36.*XZ6R;
    JW26=WI16.*XY6R + W36.*YZ6R;
    JW36=WI16.*XZ6R + WI26.*YZ6R + W36.*ZZ6R;
    KW16=-(JW26.*W36) + JW36.*WI26;
    KW26=JW16.*W36 - JW36.*WI16;
    KW36=JW26.*WI16 - JW16.*WI26;
    SW16=-(MX6R.*W36.^2) + WI26.*(MY6R.*WI16 - MX6R.*WI26);
    SW26=-(MY6R.*W36.^2) - WI16.*(MY6R.*WI16 - MX6R.*WI26);
    SW36=MX6R.*W36.*WI16 + MY6R.*W36.*WI26;
    WQ16=QP6.*WI26;
    WQ26=-(QP6.*WI16);
    LW16=A316.*D6.*W35.*WI15 + A216.*D6.*WI15.*WI25 + C6.*(-(D6.*W35.^2)
- D6.*WI25.^2);
    LW26=A326.*D6.*W35.*WI15 + A226.*D6.*WI15.*WI25 - S6.*(-(D6.*W35.^2)
- D6.*WI25.^2);
    LW36=Ca6.*D6.*W35.*WI15 - D6.*Sa6.*WI15.*WI25;
    JW17=WI17.*XX7R + WI27.*XY7 + W37.*XZ7;
    JW27=WI17.*XY7 + W37.*YZ7;
    JW37=WI17.*XZ7 + WI27.*YZ7 + W37.*ZZ7;
    KW17=-(JW27.*W37) + JW37.*WI27;
    KW27=JW17.*W37 - JW37.*WI17;
    KW37=JW27.*WI17 - JW17.*WI27;
```

```
    SW17=-(MX7.*W37.^2) + WI27.*(MY7.*WI17 - MX7.*WI27);
    SW27=-(MY7.*W37.^2) - WI17.*(MY7.*WI17 - MX7.*WI27);
    SW37=MX7.*W37.*WI17 + MY7.*W37.*WI27;
    WQ17=QP7.*WI27;
    WQ27=-(QP7.*WI17);
    LW17=A317.*D7.*W36.*WI16 + A217.*D7.*WI16.*WI26 + C7.*(-(D7.*W36.^2)
- D7.*WI26.^2);
    LW27=A327.*D7.*W36.*WI16 + A227.*D7.*WI16.*WI26 - S7.*(-(D7.*W36.^2)
- D7.*WI26.^2);
    LW37=Ca7.*D7.*W36.*WI16 - D7.*Sa7.*WI16.*WI26;
    JD7=1./(IA7 + ZZ7);
    JU17=JD7.*XZ7;
    JU27=JD7.*YZ7;
    JU37=JD7.*ZZ7;
    JU47=-(JD7.*MY7);
    JU57=JD7.*MX7;
    GW7=-CZ7 + GAM7 - KW37 - FV7.*QP7 - FS7.*sign(QP7);
    GK117=XX7R - JU17.*XZ7;
    GK127=XY7 - JU17.*YZ7;
    GK137=XZ7 - JU17.*ZZ7;
    GK147=JU17.*MY7;
    GK157=-(JU17.*MX7);
    GK217=XY7 - JU27.*XZ7;
    GK227=-(JU27.*YZ7);
    GK237=YZ7 - JU27.*ZZ7;
    GK247=JU27.*MY7;
    GK257=-(JU27.*MX7);
    GK317=XZ7 - JU37.*XZ7;
    GK327=YZ7 - JU37.*YZ7;
    GK337=ZZ7 - JU37.*ZZ7;
    GK347=-MY7 + JU37.*MY7;
    GK357=MX7 - JU37.*MX7;
    GK417=-(JU47.*XZ7);
    GK427=-(JU47.*YZ7);
    GK437=-MY7 - JU47.*ZZ7;
    GK447=JU47.*MY7;
    GK457=-(JU47.*MX7);
    GK517=-(JU57.*XZ7);
    GK527=-(JU57.*YZ7);
    GK537=MX7 - JU57.*ZZ7;
    GK547=JU57.*MY7;
    GK557=-(JU57.*MX7);
    NG17=GK147.*LW17  +  GK157.*LW27  +  LW37.*MY7  +  GK117.*WQ17  +
GK127.*WQ27;
    NG27=GK247.*LW17  +  GK257.*LW27  -  LW37.*MX7  +  GK217.*WQ17  +
GK227.*WQ27;
    NG37=GK347.*LW17 + GK357.*LW27 + GK317.*WQ17 + GK327.*WQ27;
    NG47=GK447.*LW17 + GK457.*LW27 + GK417.*WQ17 + GK427.*WQ27;
    NG57=GK547.*LW17 + GK557.*LW27 + GK517.*WQ17 + GK527.*WQ27;
    NG67=MY7.*WQ17 - MX7.*WQ27;
    VS17=GW7.*JU17 + NG17;
    VS27=GW7.*JU27 + NG27;
    VS37=GW7.*JU37 + NG37;
    VS47=GW7.*JU47 + NG47;
    VS57=GW7.*JU57 + NG57;
    AP17=CX7 + KW17 + VS17;
    AP27=CY7 + KW27 + VS27;
    AP37=CZ7 + KW37 + VS37;
    AP47=FX7 + SW17 + VS47;
    AP57=FY7 + SW27 + VS57;
```

```
    AP67=FZ7 + NG67 + SW37;
    GX117=C7.*GK117 - GK217.*S7;
    GX127=C7.*GK127 - GK227.*S7;
    GX217=A217.*GK117 + A227.*GK217 + GK417.*JPR127 + GK517.*JPR227 +
JPR327.*MY7 - GK317.*Sa7;
    GX227=A217.*GK127 + A227.*GK227 + GK427.*JPR127 + GK527.*JPR227 -
JPR327.*MX7 - GK327.*Sa7;
    GX237=A217.*GK137 + A227.*GK237 + GK437.*JPR127 + GK537.*JPR227 -
GK337.*Sa7;
    GX247=A217.*GK147 + A227.*GK247 + GK447.*JPR127 + GK547.*JPR227 -
GK347.*Sa7;
    GX257=A217.*GK157 + A227.*GK257 + GK457.*JPR127 + GK557.*JPR227 -
GK357.*Sa7;
    GX267=-(A227.*MX7) + A217.*MY7;
    GX317=A317.*GK117 + A327.*GK217 + Ca7.*GK317 + GK417.*JPR137 +
GK517.*JPR237 + JPR337.*MY7;
    GX327=A317.*GK127 + A327.*GK227 + Ca7.*GK327 + GK427.*JPR137 +
GK527.*JPR237 - JPR337.*MX7;
    GX337=A317.*GK137 + A327.*GK237 + Ca7.*GK337 + GK437.*JPR137 +
GK537.*JPR237;
    GX347=A317.*GK147 + A327.*GK247 + Ca7.*GK347 + GK447.*JPR137 +
GK547.*JPR237;
    GX357=A317.*GK157 + A327.*GK257 + Ca7.*GK357 + GK457.*JPR137 +
GK557.*JPR237;
    GX367=-(A327.*MX7) + A317.*MY7;
    GX417=C7.*GK417 - GK517.*S7;
    GX427=C7.*GK427 - GK527.*S7;
    GX437=C7.*GK437 - GK537.*S7;
    GX447=C7.*GK447 - GK547.*S7;
    GX457=C7.*GK457 - GK557.*S7;
    GX517=A217.*GK417 + A227.*GK517 - MY7.*Sa7;
    GX527=A217.*GK427 + A227.*GK527 + MX7.*Sa7;
    GX537=A217.*GK437 + A227.*GK537;
    GX547=A217.*GK447 + A227.*GK547;
    GX557=A217.*GK457 + A227.*GK557;
    GX617=A317.*GK417 + A327.*GK517 + Ca7.*MY7;
    GX627=A317.*GK427 + A327.*GK527 - Ca7.*MX7;
    GX637=A317.*GK437 + A327.*GK537;
    GX647=A317.*GK447 + A327.*GK547;
    GX657=A317.*GK457 + A327.*GK557;
    TKT117=C7.*GX117 - GX127.*S7;
    TKT217=C7.*GX217 - GX227.*S7;
    TKT317=C7.*GX317 - GX327.*S7;
    TKT417=C7.*GX417 - GX427.*S7;
    TKT517=C7.*GX517 - GX527.*S7;
    TKT617=C7.*GX617 - GX627.*S7;
    TKT227=A217.*GX217 + A227.*GX227 + GX247.*JPR127 + GX257.*JPR227 +
GX267.*JPR327 - GX237.*Sa7;
    TKT327=A217.*GX317 + A227.*GX327 + GX347.*JPR127 + GX357.*JPR227 +
GX367.*JPR327 - GX337.*Sa7;
    TKT427=A217.*GX417 + A227.*GX427 + GX447.*JPR127 + GX457.*JPR227 -
GX437.*Sa7;
    TKT527=A217.*GX517 + A227.*GX527 + GX547.*JPR127 + GX557.*JPR227 -
GX537.*Sa7;
    TKT627=A217.*GX617 + A227.*GX627 + GX647.*JPR127 + GX657.*JPR227 -
GX637.*Sa7;
    TKT337=A317.*GX317 + A327.*GX327 + Ca7.*GX337 + GX347.*JPR137 +
GX357.*JPR237 + GX367.*JPR337;
    TKT437=A317.*GX417 + A327.*GX427 + Ca7.*GX437 + GX447.*JPR137 +
GX457.*JPR237;
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    TKT537=A317.*GX517  +  A327.*GX527  +  Ca7.*GX537  +  GX547.*JPR137  +
GX557.*JPR237;
    TKT637=A317.*GX617  +  A327.*GX627  +  Ca7.*GX637  +  GX647.*JPR137  +
GX657.*JPR237;
    TKT447=C7.*GX447 - GX457.*S7;
    TKT547=C7.*GX547 - GX557.*S7;
    TKT647=C7.*GX647 - GX657.*S7;
    TKT557=A217.*GX547 + A227.*GX557;
    TKT657=A217.*GX647 + A227.*GX657;
    TKT667=A317.*GX647 + A327.*GX657;
    MJE116=TKT117 + XX6R;
    MJE216=TKT217 + XY6R;
    MJE316=TKT317 + XZ6R;
    MJE616=MY6R + TKT617;
    MJE326=TKT327 + YZ6R;
    MJE626=-MX6R + TKT627;
    MJE336=TKT337 + ZZ6R;
    MJE436=-MY6R + TKT437;
    MJE536=MX6R + TKT537;
    VBE16=-(AP17.*C7) - CX6 - KW16 + AP27.*S7;
    VBE26=-(A217.*AP17) - A227.*AP27 - CY6 - AP47.*JPR127 - AP57.*JPR227
- AP67.*JPR327 - KW26 + AP37.*Sa7;
    VBE36=-(A317.*AP17) - A327.*AP27 - AP37.*Ca7 - CZ6 - AP47.*JPR137 -
AP57.*JPR237 - AP67.*JPR337 - KW36;
    VBE46=-(AP47.*C7) - FX6 + AP57.*S7 - SW16;
    VBE56=-(A217.*AP47) - A227.*AP57 - FY6 + AP67.*Sa7 - SW26;
    VBE66=-(A317.*AP47) - A327.*AP57 - AP67.*Ca7 - FZ6 - SW36;
    JD6=1./(IA6 + MJE336);
    JU16=JD6.*MJE316;
    JU26=JD6.*MJE326;
    JU36=JD6.*MJE336;
    JU46=JD6.*MJE436;
    JU56=JD6.*MJE536;
    JU66=JD6.*TKT637;
    GW6=GAM6 - FV6.*QP6 + VBE36 - FS6.*sign(QP6);
    GK116=MJE116 - JU16.*MJE316;
    GK126=MJE216 - JU16.*MJE326;
    GK136=MJE316 - JU16.*MJE336;
    GK146=-(JU16.*MJE436) + TKT417;
    GK156=-(JU16.*MJE536) + TKT517;
    GK166=MJE616 - JU16.*TKT637;
    GK216=MJE216 - JU26.*MJE316;
    GK226=-(JU26.*MJE326) + TKT227;
    GK236=MJE326 - JU26.*MJE336;
    GK246=-(JU26.*MJE436) + TKT427;
    GK256=-(JU26.*MJE536) + TKT527;
    GK266=MJE626 - JU26.*TKT637;
    GK316=MJE316 - JU36.*MJE316;
    GK326=MJE326 - JU36.*MJE326;
    GK336=MJE336 - JU36.*MJE336;
    GK346=MJE436 - JU36.*MJE436;
    GK356=MJE536 - JU36.*MJE536;
    GK366=TKT637 - JU36.*TKT637;
    GK416=-(JU46.*MJE316) + TKT417;
    GK426=-(JU46.*MJE326) + TKT427;
    GK436=-(JU46.*MJE336) + MJE436;
    GK446=-(JU46.*MJE436) + TKT447;
    GK456=-(JU46.*MJE536) + TKT547;
    GK466=-(JU46.*TKT637) + TKT647;
    GK516=-(JU56.*MJE316) + TKT517;
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    GK526=-(JU56.*MJE326) + TKT527;
    GK536=-(JU56.*MJE336) + MJE536;
    GK546=-(JU56.*MJE436) + TKT547;
    GK556=-(JU56.*MJE536) + TKT557;
    GK566=-(JU56.*TKT637) + TKT657;
    GK616=-(JU66.*MJE316) + MJE616;
    GK626=-(JU66.*MJE326) + MJE626;
    GK636=-(JU66.*MJE336) + TKT637;
    GK646=-(JU66.*MJE436) + TKT647;
    GK656=-(JU66.*MJE536) + TKT657;
    GK666=-(JU66.*TKT637) + TKT667;
    NG16=GK146.*LW16  +  GK156.*LW26  +  GK166.*LW36  +  GK116.*WQ16  +
GK126.*WQ26;
    NG26=GK246.*LW16  +  GK256.*LW26  +  GK266.*LW36  +  GK216.*WQ16  +
GK226.*WQ26;
    NG36=GK346.*LW16  +  GK356.*LW26  +  GK366.*LW36  +  GK316.*WQ16  +
GK326.*WQ26;
    NG46=GK446.*LW16  +  GK456.*LW26  +  GK466.*LW36  +  GK416.*WQ16  +
GK426.*WQ26;
    NG56=GK546.*LW16  +  GK556.*LW26  +  GK566.*LW36  +  GK516.*WQ16  +
GK526.*WQ26;
    NG66=GK646.*LW16  +  GK656.*LW26  +  GK666.*LW36  +  GK616.*WQ16  +
GK626.*WQ26;
    VS16=GW6.*JU16 + NG16;
    VS26=GW6.*JU26 + NG26;
    VS36=GW6.*JU36 + NG36;
    VS46=GW6.*JU46 + NG46;
    VS56=GW6.*JU56 + NG56;
    VS66=GW6.*JU66 + NG66;
    AP16=-VBE16 + VS16;
    AP26=-VBE26 + VS26;
    AP36=-VBE36 + VS36;
    AP46=-VBE46 + VS46;
    AP56=-VBE56 + VS56;
    AP66=-VBE66 + VS66;
    GX116=C6.*GK116 - GK216.*S6;
    GX126=C6.*GK126 - GK226.*S6;
    GX216=A216.*GK116  +  A226.*GK216  +  GK416.*JPR126  +  GK516.*JPR226  +
GK616.*JPR326 - GK316.*Sa6;
    GX226=A216.*GK126  +  A226.*GK226  +  GK426.*JPR126  +  GK526.*JPR226  +
GK626.*JPR326 - GK326.*Sa6;
    GX236=A216.*GK136  +  A226.*GK236  +  GK436.*JPR126  +  GK536.*JPR226  +
GK636.*JPR326 - GK336.*Sa6;
    GX246=A216.*GK146  +  A226.*GK246  +  GK446.*JPR126  +  GK546.*JPR226  +
GK646.*JPR326 - GK346.*Sa6;
    GX256=A216.*GK156  +  A226.*GK256  +  GK456.*JPR126  +  GK556.*JPR226  +
GK656.*JPR326 - GK356.*Sa6;
    GX266=A216.*GK166  +  A226.*GK266  +  GK466.*JPR126  +  GK566.*JPR226  +
GK666.*JPR326 - GK366.*Sa6;
    GX316=A316.*GK116  +  A326.*GK216  +  Ca6.*GK316  +  GK416.*JPR136  +
GK516.*JPR236 + GK616.*JPR336;
    GX326=A316.*GK126  +  A326.*GK226  +  Ca6.*GK326  +  GK426.*JPR136  +
GK526.*JPR236 + GK626.*JPR336;
    GX336=A316.*GK136  +  A326.*GK236  +  Ca6.*GK336  +  GK436.*JPR136  +
GK536.*JPR236 + GK636.*JPR336;
    GX346=A316.*GK146  +  A326.*GK246  +  Ca6.*GK346  +  GK446.*JPR136  +
GK546.*JPR236 + GK646.*JPR336;
    GX356=A316.*GK156  +  A326.*GK256  +  Ca6.*GK356  +  GK456.*JPR136  +
GK556.*JPR236 + GK656.*JPR336;
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    GX366=A316.*GK166  +  A326.*GK266  +  Ca6.*GK366  +  GK466.*JPR136  +
GK566.*JPR236 + GK666.*JPR336;
    GX416=C6.*GK416 - GK516.*S6;
    GX426=C6.*GK426 - GK526.*S6;
    GX436=C6.*GK436 - GK536.*S6;
    GX446=C6.*GK446 - GK546.*S6;
    GX456=C6.*GK456 - GK556.*S6;
    GX466=C6.*GK466 - GK566.*S6;
    GX516=A216.*GK416 + A226.*GK516 - GK616.*Sa6;
    GX526=A216.*GK426 + A226.*GK526 - GK626.*Sa6;
    GX536=A216.*GK436 + A226.*GK536 - GK636.*Sa6;
    GX546=A216.*GK446 + A226.*GK546 - GK646.*Sa6;
    GX556=A216.*GK456 + A226.*GK556 - GK656.*Sa6;
    GX566=A216.*GK466 + A226.*GK566 - GK666.*Sa6;
    GX616=A316.*GK416 + A326.*GK516 + Ca6.*GK616;
    GX626=A316.*GK426 + A326.*GK526 + Ca6.*GK626;
    GX636=A316.*GK436 + A326.*GK536 + Ca6.*GK636;
    GX646=A316.*GK446 + A326.*GK546 + Ca6.*GK646;
    GX656=A316.*GK456 + A326.*GK556 + Ca6.*GK656;
    GX666=A316.*GK466 + A326.*GK566 + Ca6.*GK666;
    TKT116=C6.*GX116 - GX126.*S6;
    TKT216=C6.*GX216 - GX226.*S6;
    TKT316=C6.*GX316 - GX326.*S6;
    TKT416=C6.*GX416 - GX426.*S6;
    TKT516=C6.*GX516 - GX526.*S6;
    TKT616=C6.*GX616 - GX626.*S6;
    TKT226=A216.*GX216  +  A226.*GX226  +  GX246.*JPR126  +  GX256.*JPR226  +
GX266.*JPR326 - GX236.*Sa6;
    TKT326=A216.*GX316  +  A226.*GX326  +  GX346.*JPR126  +  GX356.*JPR226  +
GX366.*JPR326 - GX336.*Sa6;
    TKT426=A216.*GX416  +  A226.*GX426  +  GX446.*JPR126  +  GX456.*JPR226  +
GX466.*JPR326 - GX436.*Sa6;
    TKT526=A216.*GX516  +  A226.*GX526  +  GX546.*JPR126  +  GX556.*JPR226  +
GX566.*JPR326 - GX536.*Sa6;
    TKT626=A216.*GX616  +  A226.*GX626  +  GX646.*JPR126  +  GX656.*JPR226  +
GX666.*JPR326 - GX636.*Sa6;
    TKT336=A316.*GX316  +  A326.*GX326  +  Ca6.*GX336  +  GX346.*JPR136  +
GX356.*JPR236 + GX366.*JPR336;
    TKT436=A316.*GX416  +  A326.*GX426  +  Ca6.*GX436  +  GX446.*JPR136  +
GX456.*JPR236 + GX466.*JPR336;
    TKT536=A316.*GX516  +  A326.*GX526  +  Ca6.*GX536  +  GX546.*JPR136  +
GX556.*JPR236 + GX566.*JPR336;
    TKT636=A316.*GX616  +  A326.*GX626  +  Ca6.*GX636  +  GX646.*JPR136  +
GX656.*JPR236 + GX666.*JPR336;
    TKT446=C6.*GX446 - GX456.*S6;
    TKT546=C6.*GX546 - GX556.*S6;
    TKT646=C6.*GX646 - GX656.*S6;
    TKT556=A216.*GX546 + A226.*GX556 - GX566.*Sa6;
    TKT656=A216.*GX646 + A226.*GX656 - GX666.*Sa6;
    TKT666=A316.*GX646 + A326.*GX656 + Ca6.*GX666;
    MJE115=TKT116 + XX5R;
    MJE215=TKT216 + XY5R;
    MJE315=TKT316 + XZ5R;
    MJE615=MY5R + TKT616;
    MJE325=TKT326 + YZ5R;
    MJE625=-MX5R + TKT626;
    MJE335=TKT336 + ZZ5R;
    MJE435=-MY5R + TKT436;
    MJE535=MX5R + TKT536;
    VBE15=-(AP16.*C6) - CX5 - KW15 + AP26.*S6;
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    VBE25=-(A216.*AP16) - A226.*AP26 - CY5 - AP46.*JPR126 - AP56.*JPR226
- AP66.*JPR326 - KW25 + AP36.*Sa6;
    VBE35=-(A316.*AP16) - A326.*AP26 - AP36.*Ca6 - CZ5 - AP46.*JPR136 -
AP56.*JPR236 - AP66.*JPR336 - KW35;
    VBE45=-(AP46.*C6) - FX5 + AP56.*S6 - SW15;
    VBE55=-(A216.*AP46) - A226.*AP56 - FY5 + AP66.*Sa6 - SW25;
    VBE65=-(A316.*AP46) - A326.*AP56 - AP66.*Ca6 - FZ5 - SW35;
    JD5=1./(IA5 + MJE335);
    JU15=JD5.*MJE315;
    JU25=JD5.*MJE325;
    JU35=JD5.*MJE335;
    JU45=JD5.*MJE435;
    JU55=JD5.*MJE535;
    JU65=JD5.*TKT636;
    GW5=GAM5 - FV5.*QP5 + VBE35 - FS5.*sign(QP5);
    GK115=MJE115 - JU15.*MJE315;
    GK125=MJE215 - JU15.*MJE325;
    GK135=MJE315 - JU15.*MJE335;
    GK145=-(JU15.*MJE435) + TKT416;
    GK155=-(JU15.*MJE535) + TKT516;
    GK165=MJE615 - JU15.*TKT636;
    GK215=MJE215 - JU25.*MJE315;
    GK225=-(JU25.*MJE325) + TKT226;
    GK235=MJE325 - JU25.*MJE335;
    GK245=-(JU25.*MJE435) + TKT426;
    GK255=-(JU25.*MJE535) + TKT526;
    GK265=MJE625 - JU25.*TKT636;
    GK315=MJE315 - JU35.*MJE315;
    GK325=MJE325 - JU35.*MJE325;
    GK335=MJE335 - JU35.*MJE335;
    GK345=MJE435 - JU35.*MJE435;
    GK355=MJE535 - JU35.*MJE535;
    GK365=TKT636 - JU35.*TKT636;
    GK415=-(JU45.*MJE315) + TKT416;
    GK425=-(JU45.*MJE325) + TKT426;
    GK435=-(JU45.*MJE335) + MJE435;
    GK445=-(JU45.*MJE435) + TKT446;
    GK455=-(JU45.*MJE535) + TKT546;
    GK465=-(JU45.*TKT636) + TKT646;
    GK515=-(JU55.*MJE315) + TKT516;
    GK525=-(JU55.*MJE325) + TKT526;
    GK535=-(JU55.*MJE335) + MJE535;
    GK545=-(JU55.*MJE435) + TKT546;
    GK555=-(JU55.*MJE535) + TKT556;
    GK565=-(JU55.*TKT636) + TKT656;
    GK615=-(JU65.*MJE315) + MJE615;
    GK625=-(JU65.*MJE325) + MJE625;
    GK635=-(JU65.*MJE335) + TKT636;
    GK645=-(JU65.*MJE435) + TKT646;
    GK655=-(JU65.*MJE535) + TKT656;
    GK665=-(JU65.*TKT636) + TKT666;
    NG15=GK145.*LW15  +  GK155.*LW25  +  GK165.*LW35  +  GK115.*WQ15  +
GK125.*WQ25;
    NG25=GK245.*LW15  +  GK255.*LW25  +  GK265.*LW35  +  GK215.*WQ15  +
GK225.*WQ25;
    NG35=GK345.*LW15  +  GK355.*LW25  +  GK365.*LW35  +  GK315.*WQ15  +
GK325.*WQ25;
    NG45=GK445.*LW15  +  GK455.*LW25  +  GK465.*LW35  +  GK415.*WQ15  +
GK425.*WQ25;
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    NG55=GK545.*LW15  +  GK555.*LW25  +  GK565.*LW35  +  GK515.*WQ15  +
GK525.*WQ25;
    NG65=GK645.*LW15  +  GK655.*LW25  +  GK665.*LW35  +  GK615.*WQ15  +
GK625.*WQ25;
    VS15=GW5.*JU15 + NG15;
    VS25=GW5.*JU25 + NG25;
    VS35=GW5.*JU35 + NG35;
    VS45=GW5.*JU45 + NG45;
    VS55=GW5.*JU55 + NG55;
    VS65=GW5.*JU65 + NG65;
    AP15=-VBE15 + VS15;
    AP25=-VBE25 + VS25;
    AP35=-VBE35 + VS35;
    AP45=-VBE45 + VS45;
    AP55=-VBE55 + VS55;
    AP65=-VBE65 + VS65;
    GX115=C5.*GK115 - GK215.*S5;
    GX125=C5.*GK125 - GK225.*S5;
    GX215=A215.*GK115  +  A225.*GK215  +  GK415.*JPR125  +  GK515.*JPR225  +
GK615.*JPR325 - GK315.*Sa5;
    GX225=A215.*GK125  +  A225.*GK225  +  GK425.*JPR125  +  GK525.*JPR225  +
GK625.*JPR325 - GK325.*Sa5;
    GX235=A215.*GK135  +  A225.*GK235  +  GK435.*JPR125  +  GK535.*JPR225  +
GK635.*JPR325 - GK335.*Sa5;
    GX245=A215.*GK145  +  A225.*GK245  +  GK445.*JPR125  +  GK545.*JPR225  +
GK645.*JPR325 - GK345.*Sa5;
    GX255=A215.*GK155  +  A225.*GK255  +  GK455.*JPR125  +  GK555.*JPR225  +
GK655.*JPR325 - GK355.*Sa5;
    GX265=A215.*GK165  +  A225.*GK265  +  GK465.*JPR125  +  GK565.*JPR225  +
GK665.*JPR325 - GK365.*Sa5;
    GX315=A315.*GK115  +  A325.*GK215  +  Ca5.*GK315  +  GK415.*JPR135  +
GK515.*JPR235 + GK615.*JPR335;
    GX325=A315.*GK125  +  A325.*GK225  +  Ca5.*GK325  +  GK425.*JPR135  +
GK525.*JPR235 + GK625.*JPR335;
    GX335=A315.*GK135  +  A325.*GK235  +  Ca5.*GK335  +  GK435.*JPR135  +
GK535.*JPR235 + GK635.*JPR335;
    GX345=A315.*GK145  +  A325.*GK245  +  Ca5.*GK345  +  GK445.*JPR135  +
GK545.*JPR235 + GK645.*JPR335;
    GX355=A315.*GK155  +  A325.*GK255  +  Ca5.*GK355  +  GK455.*JPR135  +
GK555.*JPR235 + GK655.*JPR335;
    GX365=A315.*GK165  +  A325.*GK265  +  Ca5.*GK365  +  GK465.*JPR135  +
GK565.*JPR235 + GK665.*JPR335;
    GX415=C5.*GK415 - GK515.*S5;
    GX425=C5.*GK425 - GK525.*S5;
    GX435=C5.*GK435 - GK535.*S5;
    GX445=C5.*GK445 - GK545.*S5;
    GX455=C5.*GK455 - GK555.*S5;
    GX465=C5.*GK465 - GK565.*S5;
    GX515=A215.*GK415 + A225.*GK515 - GK615.*Sa5;
    GX525=A215.*GK425 + A225.*GK525 - GK625.*Sa5;
    GX535=A215.*GK435 + A225.*GK535 - GK635.*Sa5;
    GX545=A215.*GK445 + A225.*GK545 - GK645.*Sa5;
    GX555=A215.*GK455 + A225.*GK555 - GK655.*Sa5;
    GX565=A215.*GK465 + A225.*GK565 - GK665.*Sa5;
    GX615=A315.*GK415 + A325.*GK515 + Ca5.*GK615;
    GX625=A315.*GK425 + A325.*GK525 + Ca5.*GK625;
    GX635=A315.*GK435 + A325.*GK535 + Ca5.*GK635;
    GX645=A315.*GK445 + A325.*GK545 + Ca5.*GK645;
    GX655=A315.*GK455 + A325.*GK555 + Ca5.*GK655;
    GX665=A315.*GK465 + A325.*GK565 + Ca5.*GK665;
```

```
    TKT115=C5.*GX115 - GX125.*S5;
    TKT215=C5.*GX215 - GX225.*S5;
    TKT315=C5.*GX315 - GX325.*S5;
    TKT415=C5.*GX415 - GX425.*S5;
    TKT515=C5.*GX515 - GX525.*S5;
    TKT615=C5.*GX615 - GX625.*S5;
    TKT225=A215.*GX215 + A225.*GX225 + GX245.*JPR125 + GX255.*JPR225 +
GX265.*JPR325 - GX235.*Sa5;
    TKT325=A215.*GX315 + A225.*GX325 + GX345.*JPR125 + GX355.*JPR225 +
GX365.*JPR325 - GX335.*Sa5;
    TKT425=A215.*GX415 + A225.*GX425 + GX445.*JPR125 + GX455.*JPR225 +
GX465.*JPR325 - GX435.*Sa5;
    TKT525=A215.*GX515 + A225.*GX525 + GX545.*JPR125 + GX555.*JPR225 +
GX565.*JPR325 - GX535.*Sa5;
    TKT625=A215.*GX615 + A225.*GX625 + GX645.*JPR125 + GX655.*JPR225 +
GX665.*JPR325 - GX635.*Sa5;
    TKT335=A315.*GX315 + A325.*GX325 + Ca5.*GX335 + GX345.*JPR135 +
GX355.*JPR235 + GX365.*JPR335;
    TKT435=A315.*GX415 + A325.*GX425 + Ca5.*GX435 + GX445.*JPR135 +
GX455.*JPR235 + GX465.*JPR335;
    TKT535=A315.*GX515 + A325.*GX525 + Ca5.*GX535 + GX545.*JPR135 +
GX555.*JPR235 + GX565.*JPR335;
    TKT635=A315.*GX615 + A325.*GX625 + Ca5.*GX635 + GX645.*JPR135 +
GX655.*JPR235 + GX665.*JPR335;
    TKT445=C5.*GX445 - GX455.*S5;
    TKT545=C5.*GX545 - GX555.*S5;
    TKT645=C5.*GX645 - GX655.*S5;
    TKT555=A215.*GX545 + A225.*GX555 - GX565.*Sa5;
    TKT655=A215.*GX645 + A225.*GX655 - GX665.*Sa5;
    TKT665=A315.*GX645 + A325.*GX655 + Ca5.*GX665;
    MJE114=TKT115 + XX4R;
    MJE214=TKT215 + XY4R;
    MJE314=TKT315 + XZ4R;
    MJE614=MY4R + TKT615;
    MJE324=TKT325 + YZ4R;
    MJE624=-MX4R + TKT625;
    MJE334=TKT335 + ZZ4R;
    MJE434=-MY4R + TKT435;
    MJE534=MX4R + TKT535;
    VBE14=-(AP15.*C5) - CX4 - KW14 + AP25.*S5;
    VBE24=-(A215.*AP15) - A225.*AP25 - CY4 - AP45.*JPR125 - AP55.*JPR225
- AP65.*JPR325 - KW24 + AP35.*Sa5;
    VBE34=-(A315.*AP15) - A325.*AP25 - AP35.*Ca5 - CZ4 - AP45.*JPR135 -
AP55.*JPR235 - AP65.*JPR335 - KW34;
    VBE44=-(AP45.*C5) - FX4 + AP55.*S5 - SW14;
    VBE54=-(A215.*AP45) - A225.*AP55 - FY4 + AP65.*Sa5 - SW24;
    VBE64=-(A315.*AP45) - A325.*AP55 - AP65.*Ca5 - FZ4 - SW34;
    JD4=1./(IA4 + MJE334);
    JU14=JD4.*MJE314;
    JU24=JD4.*MJE324;
    JU34=JD4.*MJE334;
    JU44=JD4.*MJE434;
    JU54=JD4.*MJE534;
    JU64=JD4.*TKT635;
    GW4=GAM4 - FV4.*QP4 + VBE34 - FS4.*sign(QP4);
    GK114=MJE114 - JU14.*MJE314;
    GK124=MJE214 - JU14.*MJE324;
    GK134=MJE314 - JU14.*MJE334;
    GK144=-(JU14.*MJE434) + TKT415;
    GK154=-(JU14.*MJE534) + TKT515;
```

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    GK164=MJE614 - JU14.*TKT635;
    GK214=MJE214 - JU24.*MJE314;
    GK224=-(JU24.*MJE324) + TKT225;
    GK234=MJE324 - JU24.*MJE334;
    GK244=-(JU24.*MJE434) + TKT425;
    GK254=-(JU24.*MJE534) + TKT525;
    GK264=MJE624 - JU24.*TKT635;
    GK314=MJE314 - JU34.*MJE314;
    GK324=MJE324 - JU34.*MJE324;
    GK334=MJE334 - JU34.*MJE334;
    GK344=MJE434 - JU34.*MJE434;
    GK354=MJE534 - JU34.*MJE534;
    GK364=TKT635 - JU34.*TKT635;
    GK414=-(JU44.*MJE314) + TKT415;
    GK424=-(JU44.*MJE324) + TKT425;
    GK434=-(JU44.*MJE334) + MJE434;
    GK444=-(JU44.*MJE434) + TKT445;
    GK454=-(JU44.*MJE534) + TKT545;
    GK464=-(JU44.*TKT635) + TKT645;
    GK514=-(JU54.*MJE314) + TKT515;
    GK524=-(JU54.*MJE324) + TKT525;
    GK534=-(JU54.*MJE334) + MJE534;
    GK544=-(JU54.*MJE434) + TKT545;
    GK554=-(JU54.*MJE534) + TKT555;
    GK564=-(JU54.*TKT635) + TKT655;
    GK614=-(JU64.*MJE314) + MJE614;
    GK624=-(JU64.*MJE324) + MJE624;
    GK634=-(JU64.*MJE334) + TKT635;
    GK644=-(JU64.*MJE434) + TKT645;
    GK654=-(JU64.*MJE534) + TKT655;
    GK664=-(JU64.*TKT635) + TKT665;
    NG14=GK144.*LW14  +  GK154.*LW24  +  GK164.*LW34  +  GK114.*WQ14  +
GK124.*WQ24;
    NG24=GK244.*LW14  +  GK254.*LW24  +  GK264.*LW34  +  GK214.*WQ14  +
GK224.*WQ24;
    NG34=GK344.*LW14  +  GK354.*LW24  +  GK364.*LW34  +  GK314.*WQ14  +
GK324.*WQ24;
    NG44=GK444.*LW14  +  GK454.*LW24  +  GK464.*LW34  +  GK414.*WQ14  +
GK424.*WQ24;
    NG54=GK544.*LW14  +  GK554.*LW24  +  GK564.*LW34  +  GK514.*WQ14  +
GK524.*WQ24;
    NG64=GK644.*LW14  +  GK654.*LW24  +  GK664.*LW34  +  GK614.*WQ14  +
GK624.*WQ24;
    VS14=GW4.*JU14 + NG14;
    VS24=GW4.*JU24 + NG24;
    VS34=GW4.*JU34 + NG34;
    VS44=GW4.*JU44 + NG44;
    VS54=GW4.*JU54 + NG54;
    VS64=GW4.*JU64 + NG64;
    AP14=-VBE14 + VS14;
    AP24=-VBE24 + VS24;
    AP34=-VBE34 + VS34;
    AP44=-VBE44 + VS44;
    AP54=-VBE54 + VS54;
    AP64=-VBE64 + VS64;
    GX114=C4.*GK114 - GK214.*S4;
    GX124=C4.*GK124 - GK224.*S4;
    GX214=A214.*GK114  +  A224.*GK214  +  GK414.*JPR124  +  GK514.*JPR224  +
GK614.*JPR324 - GK314.*Sa4;
```

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    GX224=A214.*GK124  +  A224.*GK224  +  GK424.*JPR124  +  GK524.*JPR224  +
GK624.*JPR324 - GK324.*Sa4;
    GX234=A214.*GK134  +  A224.*GK234  +  GK434.*JPR124  +  GK534.*JPR224  +
GK634.*JPR324 - GK334.*Sa4;
    GX244=A214.*GK144  +  A224.*GK244  +  GK444.*JPR124  +  GK544.*JPR224  +
GK644.*JPR324 - GK344.*Sa4;
    GX254=A214.*GK154  +  A224.*GK254  +  GK454.*JPR124  +  GK554.*JPR224  +
GK654.*JPR324 - GK354.*Sa4;
    GX264=A214.*GK164  +  A224.*GK264  +  GK464.*JPR124  +  GK564.*JPR224  +
GK664.*JPR324 - GK364.*Sa4;
    GX314=A314.*GK114  +  A324.*GK214  +  Ca4.*GK314  +  GK414.*JPR134  +
GK514.*JPR234 + GK614.*JPR334;
    GX324=A314.*GK124  +  A324.*GK224  +  Ca4.*GK324  +  GK424.*JPR134  +
GK524.*JPR234 + GK624.*JPR334;
    GX334=A314.*GK134  +  A324.*GK234  +  Ca4.*GK334  +  GK434.*JPR134  +
GK534.*JPR234 + GK634.*JPR334;
    GX344=A314.*GK144  +  A324.*GK244  +  Ca4.*GK344  +  GK444.*JPR134  +
GK544.*JPR234 + GK644.*JPR334;
    GX354=A314.*GK154  +  A324.*GK254  +  Ca4.*GK354  +  GK454.*JPR134  +
GK554.*JPR234 + GK654.*JPR334;
    GX364=A314.*GK164  +  A324.*GK264  +  Ca4.*GK364  +  GK464.*JPR134  +
GK564.*JPR234 + GK664.*JPR334;
    GX414=C4.*GK414 - GK514.*S4;
    GX424=C4.*GK424 - GK524.*S4;
    GX434=C4.*GK434 - GK534.*S4;
    GX444=C4.*GK444 - GK544.*S4;
    GX454=C4.*GK454 - GK554.*S4;
    GX464=C4.*GK464 - GK564.*S4;
    GX514=A214.*GK414 + A224.*GK514 - GK614.*Sa4;
    GX524=A214.*GK424 + A224.*GK524 - GK624.*Sa4;
    GX534=A214.*GK434 + A224.*GK534 - GK634.*Sa4;
    GX544=A214.*GK444 + A224.*GK544 - GK644.*Sa4;
    GX554=A214.*GK454 + A224.*GK554 - GK654.*Sa4;
    GX564=A214.*GK464 + A224.*GK564 - GK664.*Sa4;
    GX614=A314.*GK414 + A324.*GK514 + Ca4.*GK614;
    GX624=A314.*GK424 + A324.*GK524 + Ca4.*GK624;
    GX634=A314.*GK434 + A324.*GK534 + Ca4.*GK634;
    GX644=A314.*GK444 + A324.*GK544 + Ca4.*GK644;
    GX654=A314.*GK454 + A324.*GK554 + Ca4.*GK654;
    GX664=A314.*GK464 + A324.*GK564 + Ca4.*GK664;
    TKT114=C4.*GX114 - GX124.*S4;
    TKT214=C4.*GX214 - GX224.*S4;
    TKT314=C4.*GX314 - GX324.*S4;
    TKT414=C4.*GX414 - GX424.*S4;
    TKT514=C4.*GX514 - GX524.*S4;
    TKT614=C4.*GX614 - GX624.*S4;
    TKT224=A214.*GX214  +  A224.*GX224  +  GX244.*JPR124  +  GX254.*JPR224  +
GX264.*JPR324 - GX234.*Sa4;
    TKT324=A214.*GX314  +  A224.*GX324  +  GX344.*JPR124  +  GX354.*JPR224  +
GX364.*JPR324 - GX334.*Sa4;
    TKT424=A214.*GX414  +  A224.*GX424  +  GX444.*JPR124  +  GX454.*JPR224  +
GX464.*JPR324 - GX434.*Sa4;
    TKT524=A214.*GX514  +  A224.*GX524  +  GX544.*JPR124  +  GX554.*JPR224  +
GX564.*JPR324 - GX534.*Sa4;
    TKT624=A214.*GX614  +  A224.*GX624  +  GX644.*JPR124  +  GX654.*JPR224  +
GX664.*JPR324 - GX634.*Sa4;
    TKT334=A314.*GX314  +  A324.*GX324  +  Ca4.*GX334  +  GX344.*JPR134  +
GX354.*JPR234 + GX364.*JPR334;
    TKT434=A314.*GX414  +  A324.*GX424  +  Ca4.*GX434  +  GX444.*JPR134  +
GX454.*JPR234 + GX464.*JPR334;
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    TKT534=A314.*GX514  +  A324.*GX524  +  Ca4.*GX534  +  GX544.*JPR134  +
GX554.*JPR234 + GX564.*JPR334;
    TKT634=A314.*GX614  +  A324.*GX624  +  Ca4.*GX634  +  GX644.*JPR134  +
GX654.*JPR234 + GX664.*JPR334;
    TKT444=C4.*GX444 - GX454.*S4;
    TKT544=C4.*GX544 - GX554.*S4;
    TKT644=C4.*GX644 - GX654.*S4;
    TKT554=A214.*GX544 + A224.*GX554 - GX564.*Sa4;
    TKT654=A214.*GX644 + A224.*GX654 - GX664.*Sa4;
    TKT664=A314.*GX644 + A324.*GX654 + Ca4.*GX664;
    MJE113=TKT114 + XX3R;
    MJE213=TKT214 + XY3R;
    MJE313=TKT314 + XZ3R;
    MJE613=MY3R + TKT614;
    MJE323=TKT324 + YZ3R;
    MJE623=-MX3R + TKT624;
    MJE333=TKT334 + ZZ3R;
    MJE433=-MY3R + TKT434;
    MJE533=MX3R + TKT534;
    VBE13=-(AP14.*C4) - CX3 - KW13 + AP24.*S4;
    VBE23=-(A214.*AP14) - A224.*AP24 - CY3 - AP44.*JPR124 - AP54.*JPR224
- AP64.*JPR324 - KW23 + AP34.*Sa4;
    VBE33=-(A314.*AP14) - A324.*AP24 - AP34.*Ca4 - CZ3 - AP44.*JPR134 -
AP54.*JPR234 - AP64.*JPR334 - KW33;
    VBE43=-(AP44.*C4) - FX3 + AP54.*S4 - SW13;
    VBE53=-(A214.*AP44) - A224.*AP54 - FY3 + AP64.*Sa4 - SW23;
    VBE63=-(A314.*AP44) - A324.*AP54 - AP64.*Ca4 - FZ3 - SW33;
    JD3=1./(IA3 + MJE333);
    JU13=JD3.*MJE313;
    JU23=JD3.*MJE323;
    JU33=JD3.*MJE333;
    JU43=JD3.*MJE433;
    JU53=JD3.*MJE533;
    JU63=JD3.*TKT634;
    GW3=GAM3 - FV3.*QP3 + VBE33 - FS3.*sign(QP3);
    GK113=MJE113 - JU13.*MJE313;
    GK123=MJE213 - JU13.*MJE323;
    GK133=MJE313 - JU13.*MJE333;
    GK143=-(JU13.*MJE433) + TKT414;
    GK153=-(JU13.*MJE533) + TKT514;
    GK163=MJE613 - JU13.*TKT634;
    GK213=MJE213 - JU23.*MJE313;
    GK223=-(JU23.*MJE323) + TKT224;
    GK233=MJE323 - JU23.*MJE333;
    GK243=-(JU23.*MJE433) + TKT424;
    GK253=-(JU23.*MJE533) + TKT524;
    GK263=MJE623 - JU23.*TKT634;
    GK313=MJE313 - JU33.*MJE313;
    GK323=MJE323 - JU33.*MJE323;
    GK333=MJE333 - JU33.*MJE333;
    GK343=MJE433 - JU33.*MJE433;
    GK353=MJE533 - JU33.*MJE533;
    GK363=TKT634 - JU33.*TKT634;
    GK413=-(JU43.*MJE313) + TKT414;
    GK423=-(JU43.*MJE323) + TKT424;
    GK433=-(JU43.*MJE333) + MJE433;
    GK443=-(JU43.*MJE433) + TKT444;
    GK453=-(JU43.*MJE533) + TKT544;
    GK463=-(JU43.*TKT634) + TKT644;
    GK513=-(JU53.*MJE313) + TKT514;
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    GK523=-(JU53.*MJE323) + TKT524;
    GK533=-(JU53.*MJE333) + MJE533;
    GK543=-(JU53.*MJE433) + TKT544;
    GK553=-(JU53.*MJE533) + TKT554;
    GK563=-(JU53.*TKT634) + TKT654;
    GK613=-(JU63.*MJE313) + MJE613;
    GK623=-(JU63.*MJE323) + MJE623;
    GK633=-(JU63.*MJE333) + TKT634;
    GK643=-(JU63.*MJE433) + TKT644;
    GK653=-(JU63.*MJE533) + TKT654;
    GK663=-(JU63.*TKT634) + TKT664;
    NG13=GK143.*LW13  +  GK153.*LW23  +  GK163.*LW33  +  GK113.*WQ13  +
GK123.*WQ23;
    NG23=GK243.*LW13  +  GK253.*LW23  +  GK263.*LW33  +  GK213.*WQ13  +
GK223.*WQ23;
    NG33=GK343.*LW13  +  GK353.*LW23  +  GK363.*LW33  +  GK313.*WQ13  +
GK323.*WQ23;
    NG43=GK443.*LW13  +  GK453.*LW23  +  GK463.*LW33  +  GK413.*WQ13  +
GK423.*WQ23;
    NG53=GK543.*LW13  +  GK553.*LW23  +  GK563.*LW33  +  GK513.*WQ13  +
GK523.*WQ23;
    NG63=GK643.*LW13  +  GK653.*LW23  +  GK663.*LW33  +  GK613.*WQ13  +
GK623.*WQ23;
    VS13=GW3.*JU13 + NG13;
    VS23=GW3.*JU23 + NG23;
    VS33=GW3.*JU33 + NG33;
    VS43=GW3.*JU43 + NG43;
    VS53=GW3.*JU53 + NG53;
    VS63=GW3.*JU63 + NG63;
    AP13=-VBE13 + VS13;
    AP23=-VBE23 + VS23;
    AP33=-VBE33 + VS33;
    AP43=-VBE43 + VS43;
    AP53=-VBE53 + VS53;
    AP63=-VBE63 + VS63;
    GX113=C3.*GK113 - GK213.*S3;
    GX123=C3.*GK123 - GK223.*S3;
    GX213=A213.*GK113  +  A223.*GK213  +  GK413.*JPR123  +  GK513.*JPR223  +
GK613.*JPR323 - GK313.*Sa3;
    GX223=A213.*GK123  +  A223.*GK223  +  GK423.*JPR123  +  GK523.*JPR223  +
GK623.*JPR323 - GK323.*Sa3;
    GX233=A213.*GK133  +  A223.*GK233  +  GK433.*JPR123  +  GK533.*JPR223  +
GK633.*JPR323 - GK333.*Sa3;
    GX243=A213.*GK143  +  A223.*GK243  +  GK443.*JPR123  +  GK543.*JPR223  +
GK643.*JPR323 - GK343.*Sa3;
    GX253=A213.*GK153  +  A223.*GK253  +  GK453.*JPR123  +  GK553.*JPR223  +
GK653.*JPR323 - GK353.*Sa3;
    GX263=A213.*GK163  +  A223.*GK263  +  GK463.*JPR123  +  GK563.*JPR223  +
GK663.*JPR323 - GK363.*Sa3;
    GX313=A313.*GK113  +  A323.*GK213  +  Ca3.*GK313  +  GK413.*JPR133  +
GK513.*JPR233 + GK613.*JPR333;
    GX323=A313.*GK123  +  A323.*GK223  +  Ca3.*GK323  +  GK423.*JPR133  +
GK523.*JPR233 + GK623.*JPR333;
    GX333=A313.*GK133  +  A323.*GK233  +  Ca3.*GK333  +  GK433.*JPR133  +
GK533.*JPR233 + GK633.*JPR333;
    GX343=A313.*GK143  +  A323.*GK243  +  Ca3.*GK343  +  GK443.*JPR133  +
GK543.*JPR233 + GK643.*JPR333;
    GX353=A313.*GK153  +  A323.*GK253  +  Ca3.*GK353  +  GK453.*JPR133  +
GK553.*JPR233 + GK653.*JPR333;
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    GX363=A313.*GK163  +  A323.*GK263  +  Ca3.*GK363  +  GK463.*JPR133  +
GK563.*JPR233 + GK663.*JPR333;
    GX413=C3.*GK413 - GK513.*S3;
    GX423=C3.*GK423 - GK523.*S3;
    GX433=C3.*GK433 - GK533.*S3;
    GX443=C3.*GK443 - GK543.*S3;
    GX453=C3.*GK453 - GK553.*S3;
    GX463=C3.*GK463 - GK563.*S3;
    GX513=A213.*GK413 + A223.*GK513 - GK613.*Sa3;
    GX523=A213.*GK423 + A223.*GK523 - GK623.*Sa3;
    GX533=A213.*GK433 + A223.*GK533 - GK633.*Sa3;
    GX543=A213.*GK443 + A223.*GK543 - GK643.*Sa3;
    GX553=A213.*GK453 + A223.*GK553 - GK653.*Sa3;
    GX563=A213.*GK463 + A223.*GK563 - GK663.*Sa3;
    GX613=A313.*GK413 + A323.*GK513 + Ca3.*GK613;
    GX623=A313.*GK423 + A323.*GK523 + Ca3.*GK623;
    GX633=A313.*GK433 + A323.*GK533 + Ca3.*GK633;
    GX643=A313.*GK443 + A323.*GK543 + Ca3.*GK643;
    GX653=A313.*GK453 + A323.*GK553 + Ca3.*GK653;
    GX663=A313.*GK463 + A323.*GK563 + Ca3.*GK663;
    TKT113=C3.*GX113 - GX123.*S3;
    TKT213=C3.*GX213 - GX223.*S3;
    TKT313=C3.*GX313 - GX323.*S3;
    TKT413=C3.*GX413 - GX423.*S3;
    TKT513=C3.*GX513 - GX523.*S3;
    TKT613=C3.*GX613 - GX623.*S3;
    TKT223=A213.*GX213 + A223.*GX223 + GX243.*JPR123 + GX253.*JPR223 +
GX263.*JPR323 - GX233.*Sa3;
    TKT323=A213.*GX313 + A223.*GX323 + GX343.*JPR123 + GX353.*JPR223 +
GX363.*JPR323 - GX333.*Sa3;
    TKT423=A213.*GX413 + A223.*GX423 + GX443.*JPR123 + GX453.*JPR223 +
GX463.*JPR323 - GX433.*Sa3;
    TKT523=A213.*GX513 + A223.*GX523 + GX543.*JPR123 + GX553.*JPR223 +
GX563.*JPR323 - GX533.*Sa3;
    TKT623=A213.*GX613 + A223.*GX623 + GX643.*JPR123 + GX653.*JPR223 +
GX663.*JPR323 - GX633.*Sa3;
    TKT333=A313.*GX313  +  A323.*GX323  +  Ca3.*GX333  +  GX343.*JPR133  +
GX353.*JPR233 + GX363.*JPR333;
    TKT433=A313.*GX413  +  A323.*GX423  +  Ca3.*GX433  +  GX443.*JPR133  +
GX453.*JPR233 + GX463.*JPR333;
    TKT533=A313.*GX513  +  A323.*GX523  +  Ca3.*GX533  +  GX543.*JPR133  +
GX553.*JPR233 + GX563.*JPR333;
    TKT633=A313.*GX613  +  A323.*GX623  +  Ca3.*GX633  +  GX643.*JPR133  +
GX653.*JPR233 + GX663.*JPR333;
    MJE112=TKT113 + XX2R;
    MJE212=TKT213 + XY2R;
    MJE312=TKT313 + XZ2R;
    MJE612=MY2R + TKT613;
    MJE322=TKT323 + YZ2R;
    MJE622=-MX2R + TKT623;
    MJE332=TKT333 + ZZ2R;
    MJE432=-MY2R + TKT433;
    MJE532=MX2R + TKT533;
    VBE12=-(AP13.*C3) - CX2 - KW12 + AP23.*S3;
    VBE22=-(A213.*AP13) - A223.*AP23 - CY2 - AP43.*JPR123 - AP53.*JPR223
- AP63.*JPR323 - KW22 + AP33.*Sa3;
    VBE32=-(A313.*AP13) - A323.*AP23 - AP33.*Ca3 - CZ2 - AP43.*JPR133 -
AP53.*JPR233 - AP63.*JPR333 - KW32;
    JD2=1./(IA2 + MJE332);
    JU12=JD2.*MJE312;
```

```
    JU22=JD2.*MJE322;
    JU32=JD2.*MJE332;
    JU42=JD2.*MJE432;
    JU52=JD2.*MJE532;
    JU62=JD2.*TKT633;
    GW2=GAM2 - FV2.*QP2 + VBE32 - FS2.*sign(QP2);
    GK112=MJE112 - JU12.*MJE312;
    GK122=MJE212 - JU12.*MJE322;
    GK132=MJE312 - JU12.*MJE332;
    GK212=MJE212 - JU22.*MJE312;
    GK222=-(JU22.*MJE322) + TKT223;
    GK232=MJE322 - JU22.*MJE332;
    GK312=MJE312 - JU32.*MJE312;
    GK322=MJE322 - JU32.*MJE322;
    GK332=MJE332 - JU32.*MJE332;
    GK412=-(JU42.*MJE312) + TKT413;
    GK422=-(JU42.*MJE322) + TKT423;
    GK432=-(JU42.*MJE332) + MJE432;
    GK512=-(JU52.*MJE312) + TKT513;
    GK522=-(JU52.*MJE322) + TKT523;
    GK532=-(JU52.*MJE332) + MJE532;
    GK612=-(JU62.*MJE312) + MJE612;
    GK622=-(JU62.*MJE322) + MJE622;
    GK632=-(JU62.*MJE332) + TKT633;
    NG12=GK112.*WQ12 + GK122.*WQ22;
    NG22=GK212.*WQ12 + GK222.*WQ22;
    NG32=GK312.*WQ12 + GK322.*WQ22;
    VS12=GW2.*JU12 + NG12;
    VS22=GW2.*JU22 + NG22;
    VS32=GW2.*JU32 + NG32;
    AP12=-VBE12 + VS12;
    AP22=-VBE22 + VS22;
    AP32=-VBE32 + VS32;
    GX312=A312.*GK112 + A322.*GK212 + Ca2.*GK312;
    GX322=A312.*GK122 + A322.*GK222 + Ca2.*GK322;
    GX332=A312.*GK132 + A322.*GK232 + Ca2.*GK332;
    GX612=A312.*GK412 + A322.*GK512 + Ca2.*GK612;
    GX622=A312.*GK422 + A322.*GK522 + Ca2.*GK622;
    GX632=A312.*GK432 + A322.*GK532 + Ca2.*GK632;
    TKT332=A312.*GX312 + A322.*GX322 + Ca2.*GX332;
    TKT632=A312.*GX612 + A322.*GX622 + Ca2.*GX632;
    MJE331=TKT332 + ZZ1R;
    VBE31=-(A312.*AP12) - A322.*AP22 - AP32.*Ca2 - CZ1;
    JD1=1./MJE331;
    JU61=JD1.*TKT632;
    GW1=GAM1 - FV1.*QP1 + VBE31 - FS1.*sign(QP1);
    GU1=-(G3.*JU61);
    QDP1=-GU1 + GW1.*JD1;
    VR12=A312.*QDP1 + WQ12;
    VR22=A322.*QDP1 + WQ22;
    VR32=Ca2.*QDP1;
    VR42=-(A312.*G3);
    VR52=-(A322.*G3);
    VR62=-(Ca2.*G3);
    GU2=JU12.*VR12 + JU22.*VR22 + JU32.*VR32 + JU42.*VR42 + JU52.*VR52 +
JU62.*VR62;
    QDP2=-GU2 + GW2.*JD2;
    WP32=QDP2 + VR32;
    VR13=C3.*VR12 + A213.*VR22 + A313.*WP32 + WQ13;
    VR23=-(S3.*VR12) + A223.*VR22 + A323.*WP32 + WQ23;
```

```
    VR33=-(Sa3.*VR22) + Ca3.*WP32;
    VR43=LW13  +  JPR123.*VR22  +  C3.*VR42  +  A213.*VR52  +  A313.*VR62  +
JPR133.*WP32;
    VR53=LW23  +  JPR223.*VR22  -  S3.*VR42  +  A223.*VR52  +  A323.*VR62  +
JPR233.*WP32;
    VR63=LW33 + JPR323.*VR22 - Sa3.*VR52 + Ca3.*VR62 + JPR333.*WP32;
    GU3=JU13.*VR13 + JU23.*VR23 + JU33.*VR33 + JU43.*VR43 + JU53.*VR53 +
JU63.*VR63;
    QDP3=-GU3 + GW3.*JD3;
    WP33=QDP3 + VR33;
    VR14=C4.*VR13 + A214.*VR23 + A314.*WP33 + WQ14;
    VR24=-(S4.*VR13) + A224.*VR23 + A324.*WP33 + WQ24;
    VR34=-(Sa4.*VR23) + Ca4.*WP33;
    VR44=LW14  +  JPR124.*VR23  +  C4.*VR43  +  A214.*VR53  +  A314.*VR63  +
JPR134.*WP33;
    VR54=LW24  +  JPR224.*VR23  -  S4.*VR43  +  A224.*VR53  +  A324.*VR63  +
JPR234.*WP33;
    VR64=LW34 + JPR324.*VR23 - Sa4.*VR53 + Ca4.*VR63 + JPR334.*WP33;
    GU4=JU14.*VR14 + JU24.*VR24 + JU34.*VR34 + JU44.*VR44 + JU54.*VR54 +
JU64.*VR64;
    QDP4=-GU4 + GW4.*JD4;
    WP34=QDP4 + VR34;
    VR15=C5.*VR14 + A215.*VR24 + A315.*WP34 + WQ15;
    VR25=-(S5.*VR14) + A225.*VR24 + A325.*WP34 + WQ25;
    VR35=-(Sa5.*VR24) + Ca5.*WP34;
    VR45=LW15  +  JPR125.*VR24  +  C5.*VR44  +  A215.*VR54  +  A315.*VR64  +
JPR135.*WP34;
    VR55=LW25  +  JPR225.*VR24  -  S5.*VR44  +  A225.*VR54  +  A325.*VR64  +
JPR235.*WP34;
    VR65=LW35 + JPR325.*VR24 - Sa5.*VR54 + Ca5.*VR64 + JPR335.*WP34;
    GU5=JU15.*VR15 + JU25.*VR25 + JU35.*VR35 + JU45.*VR45 + JU55.*VR55 +
JU65.*VR65;
    QDP5=-GU5 + GW5.*JD5;
    WP35=QDP5 + VR35;
    VR16=C6.*VR15 + A216.*VR25 + A316.*WP35 + WQ16;
    VR26=-(S6.*VR15) + A226.*VR25 + A326.*WP35 + WQ26;
    VR36=-(Sa6.*VR25) + Ca6.*WP35;
    VR46=LW16  +  JPR126.*VR25  +  C6.*VR45  +  A216.*VR55  +  A316.*VR65  +
JPR136.*WP35;
    VR56=LW26  +  JPR226.*VR25  -  S6.*VR45  +  A226.*VR55  +  A326.*VR65  +
JPR236.*WP35;
    VR66=LW36 + JPR326.*VR25 - Sa6.*VR55 + Ca6.*VR65 + JPR336.*WP35;
    GU6=JU16.*VR16 + JU26.*VR26 + JU36.*VR36 + JU46.*VR46 + JU56.*VR56 +
JU66.*VR66;
    QDP6=-GU6 + GW6.*JD6;
    WP36=QDP6 + VR36;
    VR17=C7.*VR16 + A217.*VR26 + A317.*WP36 + WQ17;
    VR27=-(S7.*VR16) + A227.*VR26 + A327.*WP36 + WQ27;
    VR37=-(Sa7.*VR26) + Ca7.*WP36;
    VR47=LW17  +  JPR127.*VR26  +  C7.*VR46  +  A217.*VR56  +  A317.*VR66  +
JPR137.*WP36;
    VR57=LW27  +  JPR227.*VR26  -  S7.*VR46  +  A227.*VR56  +  A327.*VR66  +
JPR237.*WP36;
    GU7=JU17.*VR17 + JU27.*VR27 + JU37.*VR37 + JU47.*VR47 + JU57.*VR57;
    QDP7=-GU7 + GW7.*JD7;


% *=*
% Number of operations : 1584 '+' or '-', 2096 '*' or '/'
```

B2 MODELO DINAMICO INVERSO

El modelo dinámico inverso (MDI) obtenido del software Symoro se muestra a continuación:

```
% (*****************************************)
% (** SYMORO+ : SYmbolic MOdelling of RObots **)
% (**=====================================**)
% (**      IRCCyN-ECN - 1, rue de la Noe     **)
% (**      B.P.92101                         **)
% (**      44321 Nantes cedex 3, FRANCE      **)
% (**      www.irccyn.ec-nantes.fr           **)
% (*****************************************)


%                     Name     of     file     :     D:\Archivos     de
Programa\Irccyn\Robots\Cateter\Cateterbase.dyn



%      Geometric parameters


% j     ant   mu    sigma gamma b     alpha d     theta r


% 1     0     1     0     0     0     0     0     t1    0

%                                   pi
% 2     1     1     0     0     0     --    0     t2    0
%                                   2
%                                   pi
% 3     2     1     0     0     0     --    D3    t3    0
%                                   2
%                                   -pi
% 4     3     1     0     0     0     ---   D4    t4    0
%                                    2
%                                   pi
% 5     4     1     0     0     0     --    D5    t5    0
%                                   2
%                                   -pi
% 6     5     1     0     0     0     ---   D6    t6    0
%                                    2
%                                   pi
% 7     6     1     0     0     0     --    D7    t7    0
%                                   2



%              Inertial parameters

% j      XX     XY     XZ     YY     YZ     ZZ     MX     MY     MZ     M
Ia
```

```
% 1      0      0      0      0      0      ZZ1R   0      0      0      0
0

% 2      XX2R   XY2R   XZ2R   0      YZ2R   ZZ2R   MX2R   MY2R   0      0
IA2

% 3      XX3R   XY3R   XZ3R   0      YZ3R   ZZ3R   MX3R   MY3R   0      0
IA3

% 4      XX4R   XY4R   XZ4R   0      YZ4R   ZZ4R   MX4R   MY4R   0      0
IA4

% 5      XX5R   XY5R   XZ5R   0      YZ5R   ZZ5R   MX5R   MY5R   0      0
IA5

% 6      XX6R   XY6R   XZ6R   0      YZ6R   ZZ6R   MX6R   MY6R   0      0
IA6

% 7      XX7R   XY7    XZ7    0      YZ7    ZZ7    MX7    MY7    0      0
IA7



%      External   forces,friction   parameters,   joint   velocities   and
accelerations

% j       FX      FY      FZ      CX      CY      CZ      FS      FV      QP
QDP

% 1       FX1     FY1     FZ1     CX1     CY1     CZ1     FS1     FV1     QP1
QDP1

% 2       FX2     FY2     FZ2     CX2     CY2     CZ2     FS2     FV2     QP2
QDP2

% 3       FX3     FY3     FZ3     CX3     CY3     CZ3     FS3     FV3     QP3
QDP3

% 4       FX4     FY4     FZ4     CX4     CY4     CZ4     FS4     FV4     QP4
QDP4

% 5       FX5     FY5     FZ5     CX5     CY5     CZ5     FS5     FV5     QP5
QDP5

% 6       FX6     FY6     FZ6     CX6     CY6     CZ6     FS6     FV6     QP6
QDP6

% 7       FX7     FY7     FZ7     CX7     CY7     CZ7     FS7     FV7     QP7
QDP7

% Base velocity, base accelerations, and gravity

% j     W0     WP0    V0     VP0    G

% 1     0      0      0      0      0
```

```
% 2     0     0     0     0     0

% 3     0     0     0     0     G3

%  Dynamic model: Newton Euler method
% Equations:

% Declaration of the function
function Cateterbase_dyn()

% Declaration of global input variables
global t2 pi t3 t4 t5 t6 t7 QDP1 ZZ1R QP1
global QP2 QDP2 G3 XX2R ZZ2R XY2R XZ2R YZ2R QP3 QDP3
global D3 MX3R MY3R XX3R ZZ3R XY3R XZ3R YZ3R QP4 QDP4
global D4 MX4R MY4R XX4R ZZ4R XY4R XZ4R YZ4R QP5 QDP5
global D5 MX5R MY5R XX5R ZZ5R XY5R XZ5R YZ5R QP6 QDP6
global D6 MX6R MY6R XX6R ZZ6R XY6R XZ6R YZ6R QP7 QDP7
global D7 MX7 MY7 XX7R ZZ7 XY7 XZ7 YZ7 FX7 FY7
global FZ7 CX7 CY7 CZ7 FX6 FY6 FZ6 CX6 CY6 CZ6
global FX5 FY5 FZ5 CX5 CY5 CZ5 FX4 FY4 FZ4 CX4
global CY4 CZ4 FX3 FY3 FZ3 CX3 CY3 CZ3 CX2 MY2R
global CY2 MX2R CZ2 CZ1 FV1 FS1 IA2 FV2 FS2 IA3
global FV3 FS3 IA4 FV4 FS4 IA5 FV5 FS5 IA6 FV6
global FS6 IA7 FV7 FS7

% Declaration of global output variables
global GAM1 GAM2 GAM3 GAM4 GAM5 GAM6 GAM7

% Function description:

    S2=sin(t2);
    C2=cos(t2);
    Sa2=sin(pi./2.);
    Ca2=cos(pi./2.);
    A312=S2.*Sa2;
    A322=C2.*Sa2;
    S3=sin(t3);
    C3=cos(t3);
    Sa3=sin(pi./2.);
    Ca3=cos(pi./2.);
    A213=Ca3.*S3;
    A223=C3.*Ca3;
    A313=S3.*Sa3;
    A323=C3.*Sa3;
    S4=sin(t4);
    C4=cos(t4);
    Sa4=-sin(pi./2.);
    Ca4=cos(pi./2.);
    A214=Ca4.*S4;
    A224=C4.*Ca4;
    A314=S4.*Sa4;
    A324=C4.*Sa4;
    S5=sin(t5);
    C5=cos(t5);
    Sa5=sin(pi./2.);
    Ca5=cos(pi./2.);
    A215=Ca5.*S5;
    A225=C5.*Ca5;
```

```
    A315=S5.*Sa5;
    A325=C5.*Sa5;
    S6=sin(t6);
    C6=cos(t6);
    Sa6=-sin(pi./2.);
    Ca6=cos(pi./2.);
    A216=Ca6.*S6;
    A226=C6.*Ca6;
    A316=S6.*Sa6;
    A326=C6.*Sa6;
    S7=sin(t7);
    C7=cos(t7);
    Sa7=sin(pi./2.);
    Ca7=cos(pi./2.);
    A217=Ca7.*S7;
    A227=C7.*Ca7;
    A317=S7.*Sa7;
    A327=C7.*Sa7;
    No31=QDP1.*ZZ1R;
    WI12=A312.*QP1;
    WI22=A322.*QP1;
    WI32=Ca2.*QP1;
    W32=QP2 + WI32;
    WP12=A312.*QDP1 + QP2.*WI22;
    WP22=A322.*QDP1 - QP2.*WI12;
    WP32=Ca2.*QDP1 + QDP2;
    DV112=-WI12.^2;
    DV222=-WI22.^2;
    DV332=-W32.^2;
    DV122=WI12.*WI22;
    DV132=W32.*WI12;
    DV232=W32.*WI22;
    U112=DV222 + DV332;
    U122=DV122 - WP32;
    U132=DV132 + WP22;
    U212=DV122 + WP32;
    U232=DV232 - WP12;
    U312=DV132 - WP22;
    U322=DV232 + WP12;
    VP12=-(A312.*G3);
    VP22=-(A322.*G3);
    VP32=-(Ca2.*G3);
    PIS22=XX2R - ZZ2R;
    No12=WP12.*XX2R - U312.*XY2R + U212.*XZ2R + (-DV222 + DV332).*YZ2R +
DV232.*ZZ2R;
    No22=DV132.*PIS22 + U322.*XY2R + (DV112 - DV332).*XZ2R - U122.*YZ2R;
    No32=-(DV122.*XX2R)  +  (-DV112  +  DV222).*XY2R  -  U232.*XZ2R  +
U132.*YZ2R + WP32.*ZZ2R;
    WI13=A313.*W32 + C3.*WI12 + A213.*WI22;
    WI23=A323.*W32 - S3.*WI12 + A223.*WI22;
    WI33=Ca3.*W32 - Sa3.*WI22;
    W33=QP3 + WI33;
    WP13=QP3.*WI23 + C3.*WP12 + A213.*WP22 + A313.*WP32;
    WP23=-(QP3.*WI13) - S3.*WP12 + A223.*WP22 + A323.*WP32;
    WP33=QDP3 - Sa3.*WP22 + Ca3.*WP32;
    DV113=-WI13.^2;
    DV223=-WI23.^2;
    DV333=-W33.^2;
    DV123=WI13.*WI23;
    DV133=W33.*WI13;
```

```
    DV233=W33.*WI23;
    U113=DV223 + DV333;
    U123=DV123 - WP33;
    U133=DV133 + WP23;
    U213=DV123 + WP33;
    U223=DV113 + DV333;
    U233=DV233 - WP13;
    U313=DV133 - WP23;
    U323=DV233 + WP13;
    VSP13=D3.*U112 + VP12;
    VSP23=D3.*U212 + VP22;
    VSP33=D3.*U312 + VP32;
    VP13=C3.*VSP13 + A213.*VSP23 + A313.*VSP33;
    VP23=-(S3.*VSP13) + A223.*VSP23 + A323.*VSP33;
    VP33=-(Sa3.*VSP23) + Ca3.*VSP33;
    F13=MX3R.*U113 + MY3R.*U123;
    F23=MX3R.*U213 + MY3R.*U223;
    F33=MX3R.*U313 + MY3R.*U323;
    PIS23=XX3R - ZZ3R;
    No13=WP13.*XX3R - U313.*XY3R + U213.*XZ3R + (-DV223 + DV333).*YZ3R +
DV233.*ZZ3R;
    No23=DV133.*PIS23 + U323.*XY3R + (DV113 - DV333).*XZ3R - U123.*YZ3R;
    No33=-(DV123.*XX3R)  +  (-DV113  +  DV223).*XY3R  -  U233.*XZ3R  +
U133.*YZ3R + WP33.*ZZ3R;
    WI14=A314.*W33 + C4.*WI13 + A214.*WI23;
    WI24=A324.*W33 - S4.*WI13 + A224.*WI23;
    WI34=Ca4.*W33 - Sa4.*WI23;
    W34=QP4 + WI34;
    WP14=QP4.*WI24 + C4.*WP13 + A214.*WP23 + A314.*WP33;
    WP24=-(QP4.*WI14) - S4.*WP13 + A224.*WP23 + A324.*WP33;
    WP34=QDP4 - Sa4.*WP23 + Ca4.*WP33;
    DV114=-WI14.^2;
    DV224=-WI24.^2;
    DV334=-W34.^2;
    DV124=WI14.*WI24;
    DV134=W34.*WI14;
    DV234=W34.*WI24;
    U114=DV224 + DV334;
    U124=DV124 - WP34;
    U134=DV134 + WP24;
    U214=DV124 + WP34;
    U224=DV114 + DV334;
    U234=DV234 - WP14;
    U314=DV134 - WP24;
    U324=DV234 + WP14;
    VSP14=D4.*U113 + VP13;
    VSP24=D4.*U213 + VP23;
    VSP34=D4.*U313 + VP33;
    VP14=C4.*VSP14 + A214.*VSP24 + A314.*VSP34;
    VP24=-(S4.*VSP14) + A224.*VSP24 + A324.*VSP34;
    VP34=-(Sa4.*VSP24) + Ca4.*VSP34;
    F14=MX4R.*U114 + MY4R.*U124;
    F24=MX4R.*U214 + MY4R.*U224;
    F34=MX4R.*U314 + MY4R.*U324;
    PIS24=XX4R - ZZ4R;
    No14=WP14.*XX4R - U314.*XY4R + U214.*XZ4R + (-DV224 + DV334).*YZ4R +
DV234.*ZZ4R;
    No24=DV134.*PIS24 + U324.*XY4R + (DV114 - DV334).*XZ4R - U124.*YZ4R;
    No34=-(DV124.*XX4R)  +  (-DV114  +  DV224).*XY4R  -  U234.*XZ4R  +
U134.*YZ4R + WP34.*ZZ4R;
```

```
    WI15=A315.*W34 + C5.*WI14 + A215.*WI24;
    WI25=A325.*W34 - S5.*WI14 + A225.*WI24;
    WI35=Ca5.*W34 - Sa5.*WI24;
    W35=QP5 + WI35;
    WP15=QP5.*WI25 + C5.*WP14 + A215.*WP24 + A315.*WP34;
    WP25=-(QP5.*WI15) - S5.*WP14 + A225.*WP24 + A325.*WP34;
    WP35=QDP5 - Sa5.*WP24 + Ca5.*WP34;
    DV115=-WI15.^2;
    DV225=-WI25.^2;
    DV335=-W35.^2;
    DV125=WI15.*WI25;
    DV135=W35.*WI15;
    DV235=W35.*WI25;
    U115=DV225 + DV335;
    U125=DV125 - WP35;
    U135=DV135 + WP25;
    U215=DV125 + WP35;
    U225=DV115 + DV335;
    U235=DV235 - WP15;
    U315=DV135 - WP25;
    U325=DV235 + WP15;
    VSP15=D5.*U114 + VP14;
    VSP25=D5.*U214 + VP24;
    VSP35=D5.*U314 + VP34;
    VP15=C5.*VSP15 + A215.*VSP25 + A315.*VSP35;
    VP25=-(S5.*VSP15) + A225.*VSP25 + A325.*VSP35;
    VP35=-(Sa5.*VSP25) + Ca5.*VSP35;
    F15=MX5R.*U115 + MY5R.*U125;
    F25=MX5R.*U215 + MY5R.*U225;
    F35=MX5R.*U315 + MY5R.*U325;
    PIS25=XX5R - ZZ5R;
    No15=WP15.*XX5R - U315.*XY5R + U215.*XZ5R + (-DV225 + DV335).*YZ5R +
DV235.*ZZ5R;
    No25=DV135.*PIS25 + U325.*XY5R + (DV115 - DV335).*XZ5R - U125.*YZ5R;
    No35=-(DV125.*XX5R)  +  (-DV115  +  DV225).*XY5R  -  U235.*XZ5R  +
U135.*YZ5R + WP35.*ZZ5R;
    WI16=A316.*W35 + C6.*WI15 + A216.*WI25;
    WI26=A326.*W35 - S6.*WI15 + A226.*WI25;
    WI36=Ca6.*W35 - Sa6.*WI25;
    W36=QP6 + WI36;
    WP16=QP6.*WI26 + C6.*WP15 + A216.*WP25 + A316.*WP35;
    WP26=-(QP6.*WI16) - S6.*WP15 + A226.*WP25 + A326.*WP35;
    WP36=QDP6 - Sa6.*WP25 + Ca6.*WP35;
    DV116=-WI16.^2;
    DV226=-WI26.^2;
    DV336=-W36.^2;
    DV126=WI16.*WI26;
    DV136=W36.*WI16;
    DV236=W36.*WI26;
    U116=DV226 + DV336;
    U126=DV126 - WP36;
    U136=DV136 + WP26;
    U216=DV126 + WP36;
    U226=DV116 + DV336;
    U236=DV236 - WP16;
    U316=DV136 - WP26;
    U326=DV236 + WP16;
    VSP16=D6.*U115 + VP15;
    VSP26=D6.*U215 + VP25;
    VSP36=D6.*U315 + VP35;
```

```
    VP16=C6.*VSP16 + A216.*VSP26 + A316.*VSP36;
    VP26=-(S6.*VSP16) + A226.*VSP26 + A326.*VSP36;
    VP36=-(Sa6.*VSP26) + Ca6.*VSP36;
    F16=MX6R.*U116 + MY6R.*U126;
    F26=MX6R.*U216 + MY6R.*U226;
    F36=MX6R.*U316 + MY6R.*U326;
    PIS26=XX6R - ZZ6R;
    No16=WP16.*XX6R - U316.*XY6R + U216.*XZ6R + (-DV226 + DV336).*YZ6R +
DV236.*ZZ6R;
    No26=DV136.*PIS26 + U326.*XY6R + (DV116 - DV336).*XZ6R - U126.*YZ6R;
    No36=-(DV126.*XX6R)  +  (-DV116  +  DV226).*XY6R  -  U236.*XZ6R  +
U136.*YZ6R + WP36.*ZZ6R;
    WI17=A317.*W36 + C7.*WI16 + A217.*WI26;
    WI27=A327.*W36 - S7.*WI16 + A227.*WI26;
    WI37=Ca7.*W36 - Sa7.*WI26;
    W37=QP7 + WI37;
    WP17=QP7.*WI27 + C7.*WP16 + A217.*WP26 + A317.*WP36;
    WP27=-(QP7.*WI17) - S7.*WP16 + A227.*WP26 + A327.*WP36;
    WP37=QDP7 - Sa7.*WP26 + Ca7.*WP36;
    DV117=-WI17.^2;
    DV227=-WI27.^2;
    DV337=-W37.^2;
    DV127=WI17.*WI27;
    DV137=W37.*WI17;
    DV237=W37.*WI27;
    U117=DV227 + DV337;
    U127=DV127 - WP37;
    U137=DV137 + WP27;
    U217=DV127 + WP37;
    U227=DV117 + DV337;
    U237=DV237 - WP17;
    U317=DV137 - WP27;
    U327=DV237 + WP17;
    VSP17=D7.*U116 + VP16;
    VSP27=D7.*U216 + VP26;
    VSP37=D7.*U316 + VP36;
    VP17=C7.*VSP17 + A217.*VSP27 + A317.*VSP37;
    VP27=-(S7.*VSP17) + A227.*VSP27 + A327.*VSP37;
    VP37=-(Sa7.*VSP27) + Ca7.*VSP37;
    F17=MX7.*U117 + MY7.*U127;
    F27=MX7.*U217 + MY7.*U227;
    F37=MX7.*U317 + MY7.*U327;
    PIS27=XX7R - ZZ7;
    No17=WP17.*XX7R  -  U317.*XY7  +  U217.*XZ7  +  (-DV227  +  DV337).*YZ7  +
DV237.*ZZ7;
    No27=DV137.*PIS27 + U327.*XY7 + (DV117 - DV337).*XZ7 - U127.*YZ7;
    No37=-(DV127.*XX7R) + (-DV117 + DV227).*XY7 - U237.*XZ7 + U137.*YZ7 +
WP37.*ZZ7;
    E17=F17 + FX7;
    E27=F27 + FY7;
    E37=F37 + FZ7;
    N17=CX7 + No17 + MY7.*VP37;
    N27=CY7 + No27 - MX7.*VP37;
    N37=CZ7 + No37 - MY7.*VP17 + MX7.*VP27;
    FDI17=C7.*E17 - E27.*S7;
    FDI27=A217.*E17 + A227.*E27 - E37.*Sa7;
    FDI37=A317.*E17 + A327.*E27 + Ca7.*E37;
    E16=F16 + FDI17 + FX6;
    E26=F26 + FDI27 + FY6;
    E36=F36 + FDI37 + FZ6;
```

```
    N16=CX6 + C7.*N17 + No16 - N27.*S7 + MY6R.*VP36;
    N26=CY6 - D7.*FDI37 + A217.*N17 + A227.*N27 + No26 - N37.*Sa7 -
MX6R.*VP36;
    N36=CZ6 + D7.*FDI27 + A317.*N17 + A327.*N27 + Ca7.*N37 + No36 -
MY6R.*VP16 + MX6R.*VP26;
    FDI16=C6.*E16 - E26.*S6;
    FDI26=A216.*E16 + A226.*E26 - E36.*Sa6;
    FDI36=A316.*E16 + A326.*E26 + Ca6.*E36;
    E15=F15 + FDI16 + FX5;
    E25=F25 + FDI26 + FY5;
    E35=F35 + FDI36 + FZ5;
    N15=CX5 + C6.*N16 + No15 - N26.*S6 + MY5R.*VP35;
    N25=CY5 - D6.*FDI36 + A216.*N16 + A226.*N26 + No25 - N36.*Sa6 -
MX5R.*VP35;
    N35=CZ5 + D6.*FDI26 + A316.*N16 + A326.*N26 + Ca6.*N36 + No35 -
MY5R.*VP15 + MX5R.*VP25;
    FDI15=C5.*E15 - E25.*S5;
    FDI25=A215.*E15 + A225.*E25 - E35.*Sa5;
    FDI35=A315.*E15 + A325.*E25 + Ca5.*E35;
    E14=F14 + FDI15 + FX4;
    E24=F24 + FDI25 + FY4;
    E34=F34 + FDI35 + FZ4;
    N14=CX4 + C5.*N15 + No14 - N25.*S5 + MY4R.*VP34;
    N24=CY4 - D5.*FDI35 + A215.*N15 + A225.*N25 + No24 - N35.*Sa5 -
MX4R.*VP34;
    N34=CZ4 + D5.*FDI25 + A315.*N15 + A325.*N25 + Ca5.*N35 + No34 -
MY4R.*VP14 + MX4R.*VP24;
    FDI14=C4.*E14 - E24.*S4;
    FDI24=A214.*E14 + A224.*E24 - E34.*Sa4;
    FDI34=A314.*E14 + A324.*E24 + Ca4.*E34;
    E13=F13 + FDI14 + FX3;
    E23=F23 + FDI24 + FY3;
    E33=F33 + FDI34 + FZ3;
    N13=CX3 + C4.*N14 + No13 - N24.*S4 + MY3R.*VP33;
    N23=CY3 - D4.*FDI34 + A214.*N14 + A224.*N24 + No23 - N34.*Sa4 -
MX3R.*VP33;
    N33=CZ3 + D4.*FDI24 + A314.*N14 + A324.*N24 + Ca4.*N34 + No33 -
MY3R.*VP13 + MX3R.*VP23;
    FDI23=A213.*E13 + A223.*E23 - E33.*Sa3;
    FDI33=A313.*E13 + A323.*E23 + Ca3.*E33;
    N12=CX2 + C3.*N13 + No12 - N23.*S3 + MY2R.*VP32;
    N22=CY2 - D3.*FDI33 + A213.*N13 + A223.*N23 + No22 - N33.*Sa3 -
MX2R.*VP32;
    N32=CZ2 + D3.*FDI23 + A313.*N13 + A323.*N23 + Ca3.*N33 + No32 -
MY2R.*VP12 + MX2R.*VP22;
    N31=CZ1 + A312.*N12 + A322.*N22 + Ca2.*N32 + No31;
    GAM1=N31 + FV1.*QP1 + FS1.*sign(QP1);
    GAM2=N32 + IA2.*QDP2 + FV2.*QP2 + FS2.*sign(QP2);
    GAM3=N33 + IA3.*QDP3 + FV3.*QP3 + FS3.*sign(QP3);
    GAM4=N34 + IA4.*QDP4 + FV4.*QP4 + FS4.*sign(QP4);
    GAM5=N35 + IA5.*QDP5 + FV5.*QP5 + FS5.*sign(QP5);
    GAM6=N36 + IA6.*QDP6 + FV6.*QP6 + FS6.*sign(QP6);
    GAM7=N37 + IA7.*QDP7 + FV7.*QP7 + FS7.*sign(QP7);


% *=*
% Number of operations : 433 '+' or '-', 476 '*' or '/'
```

ANEXO C: CODIGO CALCULO PSEUDOINVERSA

El código para el cálculo de la pseudoinversa de la matriz jacobiana, consta de dos algoritmos, el primero es el código principal, donde se asignan la matriz Ba [i][j] (matriz a invertir) y se hace el llamado al segundo algoritmo, que es el encargado de hacer los cálculos matriciales.

Código principal:

```
float **s, **p, **T;
	int rank;

	// calculo pseudionversa

	p = new float* [6];
	for(int i=0;i<7; i++)
		p[i] = new float[7];

	T = new float* [6];

	for(int i=0;i<7; i++)
		T[i] = new float[7];

	for(int i = 0; i<6;i++)
	{
		for(int j = 0; j<7;j++)
		{
			p[i][j] = Ba[i][j];
			T[i][j] = Ba[i][j];
		}
		//p = T;
	}
	Matriz_escalonada_reducida m;
	rank = m.rank(p,6,7);
	s = m.Matriz_Aumentada(T,6,7,rank);
```

El cálculo matricial es realizado por el siguiente algoritmo:

```
#include "StdAfx.h"
#include "Matriz_escalonada_reducida.h"

Matriz_escalonada_reducida::Matriz_escalonada_reducida(void)
{
}

float** Matriz_escalonada_reducida::Matriz_Aumentada(float **A, int row, int col,
int rank)
{
	float **M, **I;

	I = new float* [row];
	for(int i=0;i<row; i++)
		I[i] = new float[row];
	M = new float* [row];
	for(int i=0;i<col; i++)
```

```
			M[i] = new float[col + row];
		for(int i=0; i < row; i++)
		{
			for(int j = 0; j < (col + row);j++)
			{
				if(i==j)
					I[i][j] = 1;
				else
					I[i][j] = 0;
			}
		}
		for(int i=0; i < row; i++)
		{
			for(int j = 0; j < (col + row);j++)
			{
				if(j < col)
				{
					M[i][j] = A[i][j];

				}else
				{
					M[i][j] = I[i][j-col];
				}

			}


		}


		return Escalonar(Bloques(Escalonar(M,6,13),6,13,7,A,rank),6,13);
}
Matriz_escalonada_reducida::~Matriz_escalonada_reducida(void)
{
}
float ** Matriz_escalonada_reducida::Escalonar(float **M, int row, int col)
{

		bool fpV = true, control = true;
		int i = 0, j = 0, posMax=0;
		float swap = 0, pV=1, aux;
		while((i < row)&&(j< col))
		{
			float mayor =0;
			control = true;
			mayor = fabs(M[i][j]);
			posMax = i;
			for(int f = i; f < row; f++)
			{
				if(mayor < fabs(M[f][j]))
				{
					mayor = fabs(M[f][j]);
					posMax = f - i;
					control = false;
				}
			}
			if(control)
				posMax = posMax - i;
			posMax = posMax+i;
			if(mayor ==0)
			{
```

```
                for(int f = i;f<row;f++)
                        M[f][j] = 0;
                j++;
        }else
        {
                fpV = true;
                for(int c = j; c < col; c++)
                {
                        swap = M[i][c];
                        M[i][c] = M[posMax][c];
                        M[posMax][c] = swap;
                        if(fpV)
                        {
                                pV = M[i][j];
                                fpV = false;
                        }
                        M[i][c] = M[i][c]/pV;

                }
                for(int f=0;f<row;f++)
                {
                        aux = M[f][j];
                        for(int c =0; c<col;c++)
                        {
                                if(i == f)
                                        break;
                                else
                                {
                                        M[f][c] = M[f][c] - aux*M[i][c];
                                }
                        }
                }


                i++;
                j++;
        }


        }

        return M;


}
float  **  Matriz_escalonada_reducida::Bloques(float  **M,  int  Row,  int  Col,  int
ColA,float **A, int rank)
{

        int  jj = 0, ii = 0;
        float **E, **P, **Cero, **P1, **C;
        C = new float* [rank];
        for(int i=0;i<Row; i++)
                C[i] = new float[Row];
        E = new float* [rank];
        for(int i=0;i<ColA; i++)
                E[i] = new float[ColA];
        P = new float* [rank];
        for(int i=0;i<Row; i++)
                P[i] = new float[Row];
        Cero = new float* [Row - rank];
```

```
    for(int i=0;i<ColA; i++)
           Cero[i] = new float[ColA];
    P1 = new float* [Row - rank];
    for(int i=0;i<Row; i++)
           P1[i] = new float[Row];
    if(rank < Row)
    {
           for(int i=0;i < Row; i++)
           {
                  jj = 0;
                  for(int j=0;j < Col; j++)
                  {
                         if( i < rank)
                         {
                                if(j < ColA)
                                {
                                       E[i][j] = M[i][j];

                                }
                                else
                                {
                                       P[i][jj] = M[i][j];
                                       jj++;
                                }
                         }else
                         {
                                if(j < ColA)
                                       Cero[ii][j] = M[i][j];
                                else
                                {
                                       P1[ii][jj] = M[i][j];
                                       jj++;
                                }

                         }
                  }

           }
    }
    else
    {
           for(int i = 0; i< Row; i++)
           {
                  for(int j = 0; j< Col; j++)
                  {
                         if(j < ColA)
                                E[i][j] = M[i][j];
                         else
                                P[i][j-ColA] = M[i][j];
                  }
           }
    }

    for (int i=0;i<rank;i++)
{
           for (int j=0;j< Row;j++)
     {
                  C[i][j]=0;
                  for (int k=0;k<ColA;k++)
                  {
                         C[i][j]=C[i][j]+E[i][k]*A[j][k];
```

```
                }

        }
    }
    if(rank < Row)
    {
        for(int i = 0; i < Row; i++)
        {
            for(int j = 0; j < Col; j++)
            {
                if(i < rank)
                {
                    if(j < 6)
                        M[i][j] = C[i][j];
                    else
                        M[i][j] = E[i][j-3];
                }else
                {
                    if(j < 6)
                        M[i][j] = P1[i-2][j];
                    else
                        M[i][j] = Cero[i-2][j-3];
                }
            }
        }
    }else
    {
        for(int i = 0; i < Row; i++)
        {
            for(int j = 0; j < Col; j++)
            {
                if(j < Row)
                    M[i][j] = C[i][j];
                else
                    M[i][j] = E[i][j - Row];
            }
        }
    }

            return M;

}

int Matriz_escalonada_reducida::rank(float **M, int row, int col)
{
    int rank = 0;
    M = Escalonar(M, row, col);
    for(int i=0;i<row;i++)
    {
        for(int j=0;j<col;j++)
        {
            if(M[i][j] ==1)
            {
                rank++;
                break;
            }
        }
    }
    return rank;

}
```

```
void Matriz_escalonada_reducida::imprimir(float **M, int Row, int Col)
{
	printf("imprimir Matriz \n\n");
		for(int s =0; s < Row; s++)
		{
			for(int t =0; t < Col; t++)
				printf("%.3f  ", M[s][t]);
			printf("\n");

		}
		printf("\n _____________________________________");
}
```

ANEXO D: INSTALACION SOFTWARE UTILIZADO

D1 INSTALACIÓN VISUAL STUDIO

En la instalación de software Visual Studio, se utilizó la versión 2010 Ultimate, en este software solo se utiliza el lenguaje C++.

D2 INSTALACIÓN QT

Para la instalación de Qt se requiere la instalación previa de Visual Studio 2010 Ultimate.

Para este proyecto utilizamos la versión 2010 de Qt 2.3.0, este programa se puede descargar de la página oficial de QT.

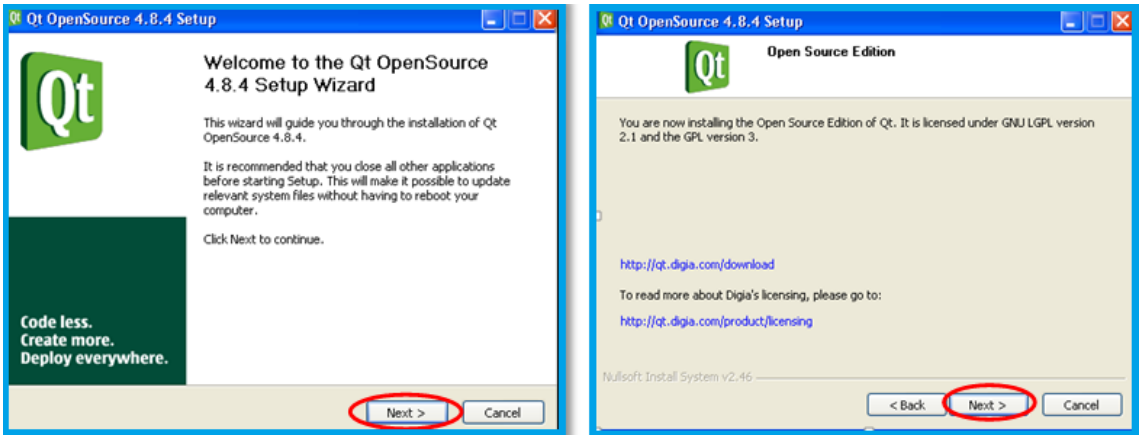

Figura D1. Iniciando con la instalación de Qt.

Se sigue con la instalación, se aceptan los términos de la licencia y seguimos con la instalación hasta terminar.

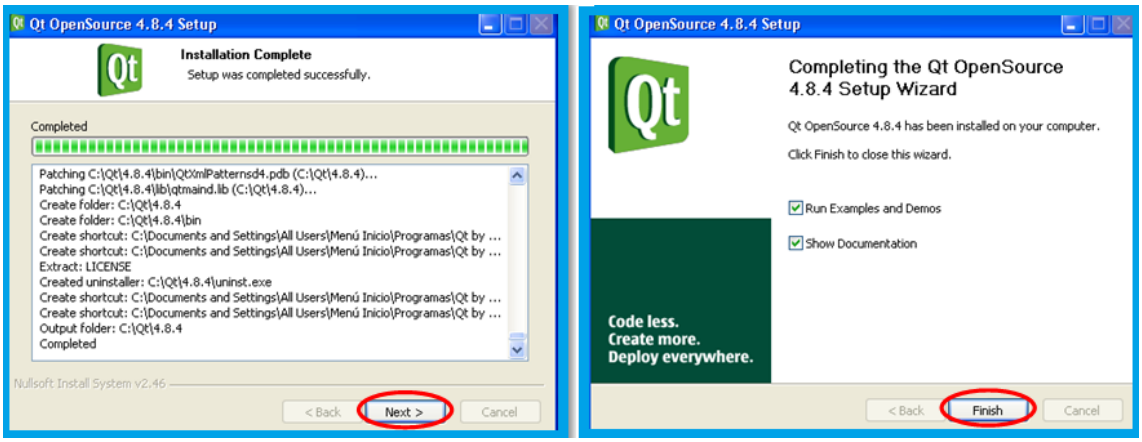

Figura D2. Instalación de Qt finalizada.

A continuación procedemos a instalar las librerías adicionales, ejecutamos el archivo ‘qt-vs-admin-1.1.11-opensource.exe’, lo anterior con el fin asociar Qt con Visual Studio 2010 Ultimate. Se aceptan los términos y condiciones y se da la opción siguiente, luego la opción instalar nuevamente siguiente y veremos una ventana donde se muestra que el software ha sido instalado.

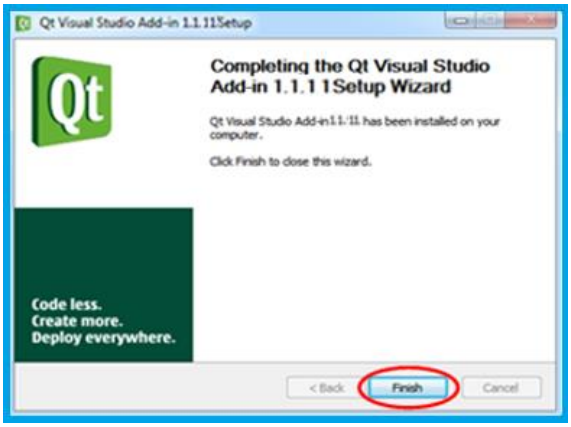

Figura D3. Instalación de librerías finalizada.

Ahora procedemos a definir las variables de entorno del sistema, se puede acceder desde panel de control o inicio -> variables de entorno. Clic sobre esta opción y se despliega la siguiente ventana.

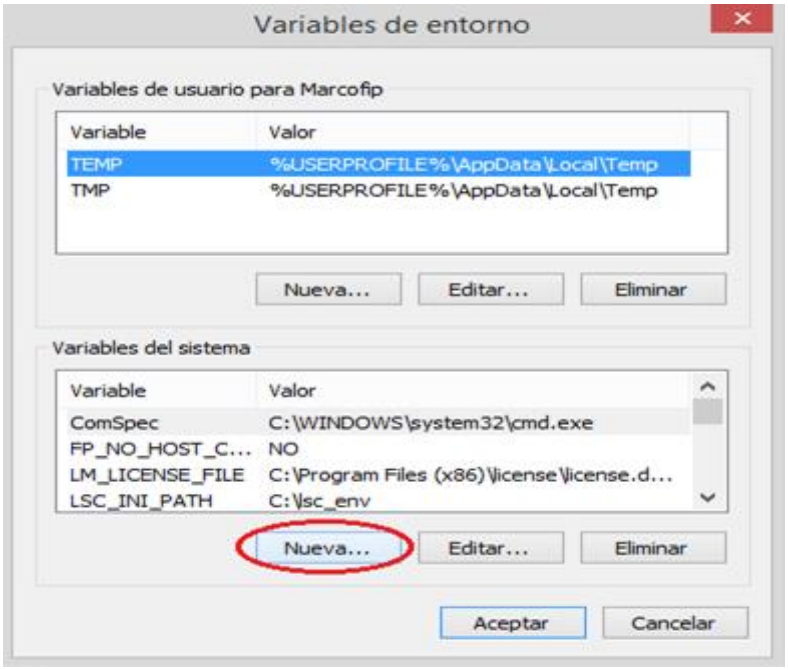

Figura D4. Variables de entorno.

Clic sobre la opción Nueva, y completamos los campos con el nombre de la variable y el valor de la variable.

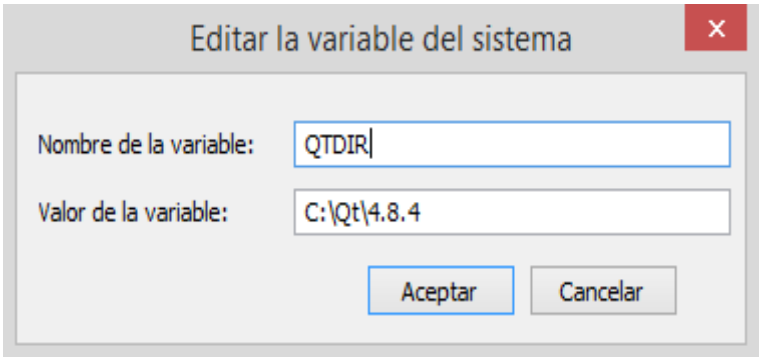

Figura D5. Creando nuevas variables de entorno.

Seguido a esto editamos el 'path' que aparece en variables del sistema y adicionamos (;%QTDIR%\bin).

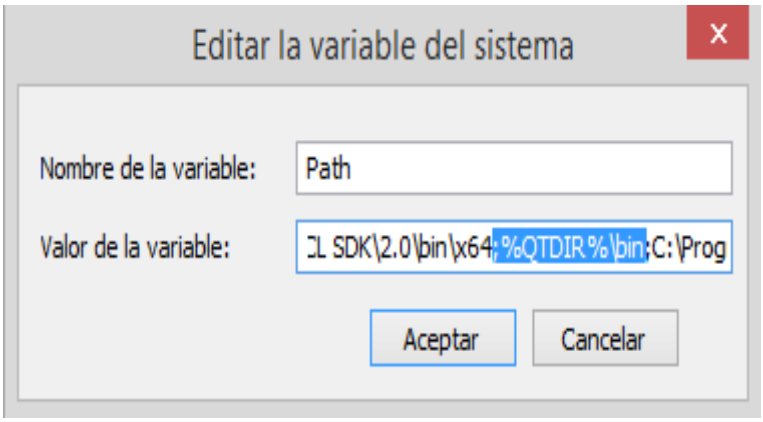

Figura D6. Edición valor de la variable path.

Finalmente cliqueamos en la opción 'Aceptar' y se cierra la ventana.

D3 INSTALACIÓN CMAKE

Instalamos la aplicación CMake V.2.8.5, esta instalación se realiza como administrador. Se aceptan las condiciones y los términos de licencia. Ahora en 'Install Options' seleccionamos 'Add CMake to the system PATH for all users'.

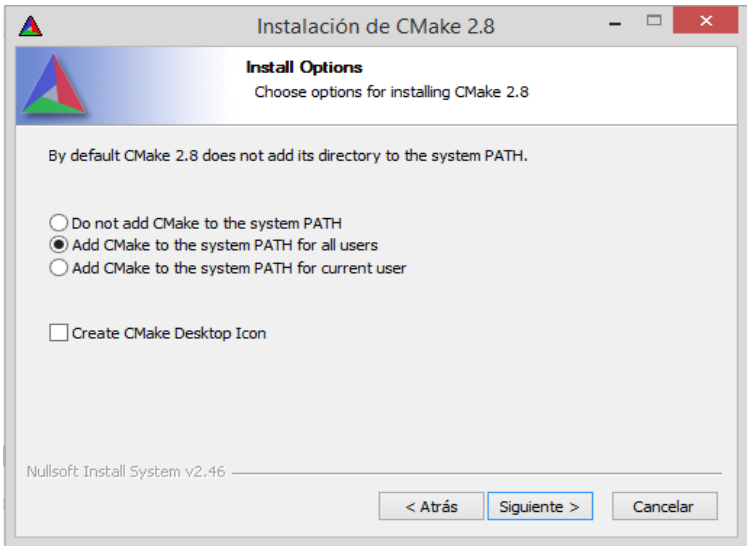

Figura D7. Instalación CMake.

Al finalizar la instalación y después de mostrar la ubicación donde se efectuara la aplicación, emerge una ventana con el mensaje de ejecución con éxito.

Figura D8. Inicio CMake.

D4 INSTALACIÓN LIBRERÍAS VTK

Para la instalación de librerías VTK se requiere instalación previa de visual studio 2010, Qt y CMake 2.8.5. El paquete de librerías VTK se debe se debe ubicar en el disco C, y se debe crear una carpeta nueva (VTK_build) ubicada dentro de la unidad donde están las librerías VTK, en la carpeta VTK_build se almacenaran los archivos generados después de la compilación.

Para la compilación ejecutamos el programa CMake y en la ventana emergente en la opción 'Where is the source code' colocamos el path de VTK (C: \VTK), en la opción ' Where to build the binaries' colocamos el path de la carpeta VTK_build (C:\VTK_build).

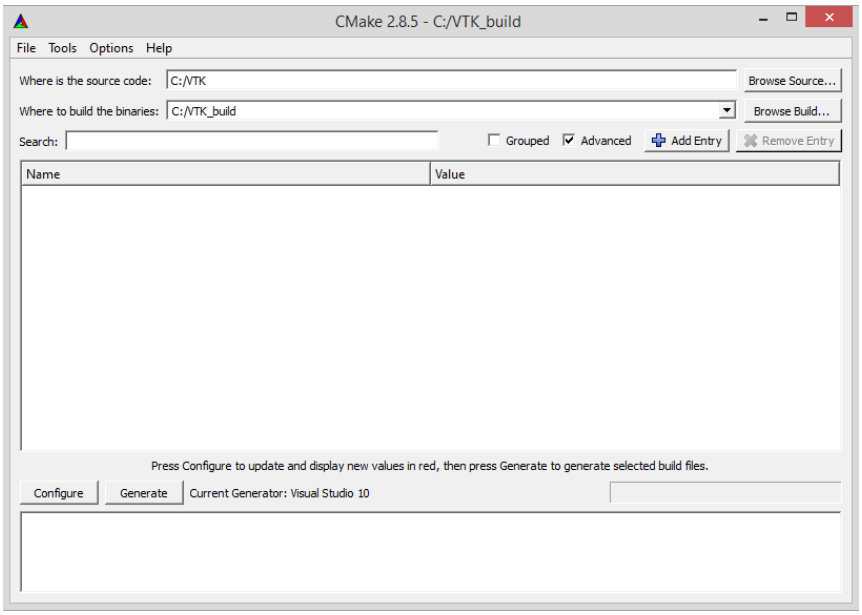

Figura D9. Generando el código CMake

A continuación damos clic en 'Advance', luego en la opción 'configure' posteriormente especificamos el tipo de generador para nuestro proyecto es Visual Studio 2010, y damos clic en la opción 'Finish'.

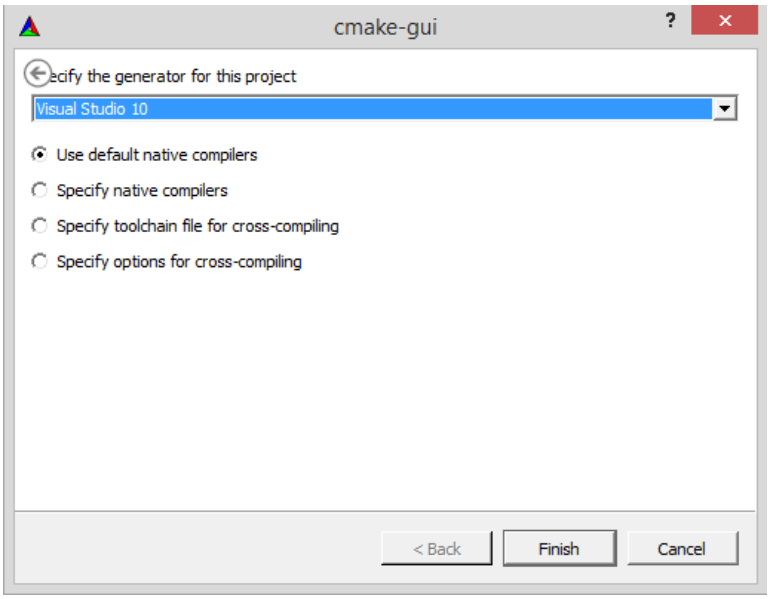

Figura D10. Especificaciones para el generador del proyecto

En la ventana principal de CMake se observa unas opciones resaltadas en color rojo, en este caso seleccionamos las opciones 'BUILD_EXAMPLES' y 'VTK_USE_QT'.

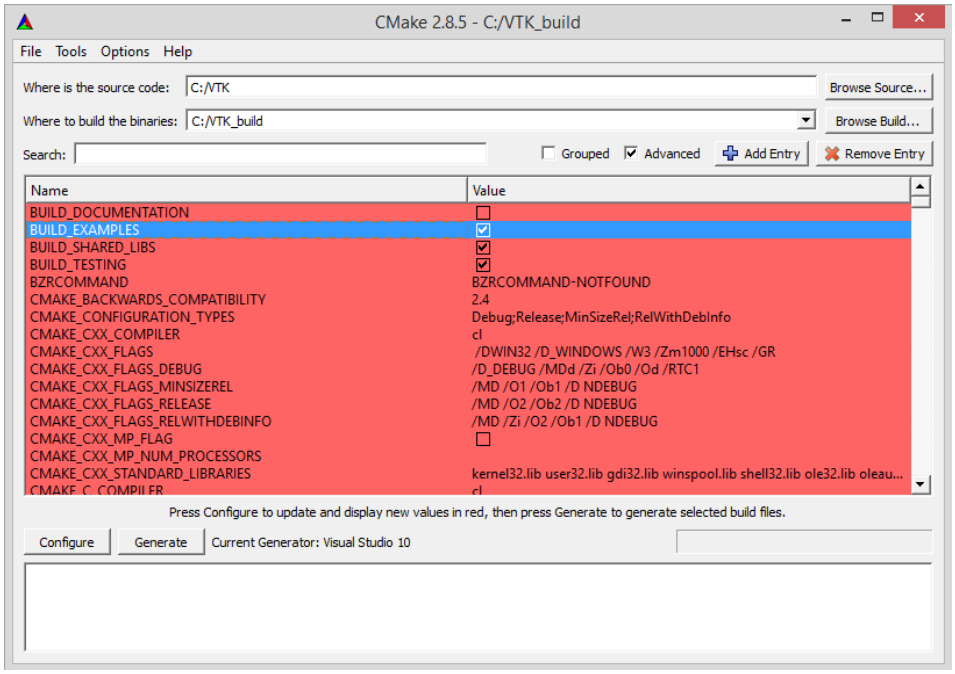

Figura D11. Asignación de VTK en Qt

Ahora damos clic en la opción ‘configure’, nuevamente aparece unas opciones resaltadas en color rojo en este caso se debe dar la ruta donde está el ejecutable qmake.exe; la ruta a colocar es “C:/Qt/4.8.4/bin/qmake.exe”, la otra opción a marcar es ‘VTK_USE_QVTK_QTOPENGL’, luego damos clic en ‘configure’, nuevamente aparecen opciones en rojo, solo damos clic en ‘configure’ por segunda vez y ya no deben aparecer más opciones en color, damos clic en la opción ‘Generate’, y cerramos la aplicación CMake.

Ahora nos ubicamos en la ruta de la carpeta nueva llamada VTK_build, aquí se encuentran los archivos generados y buscamos el fichero VTK.sln, para abrir este fichero debemos abrir el fichero como proyecto, una vez cargado el proyecto en visual, se inicia la compilación de la biblioteca VTK en Visual Studio, escogemos el fichero “ALL_BUILD”, damos clic derecho sobre este fichero y escogemos l opción ‘generar’.

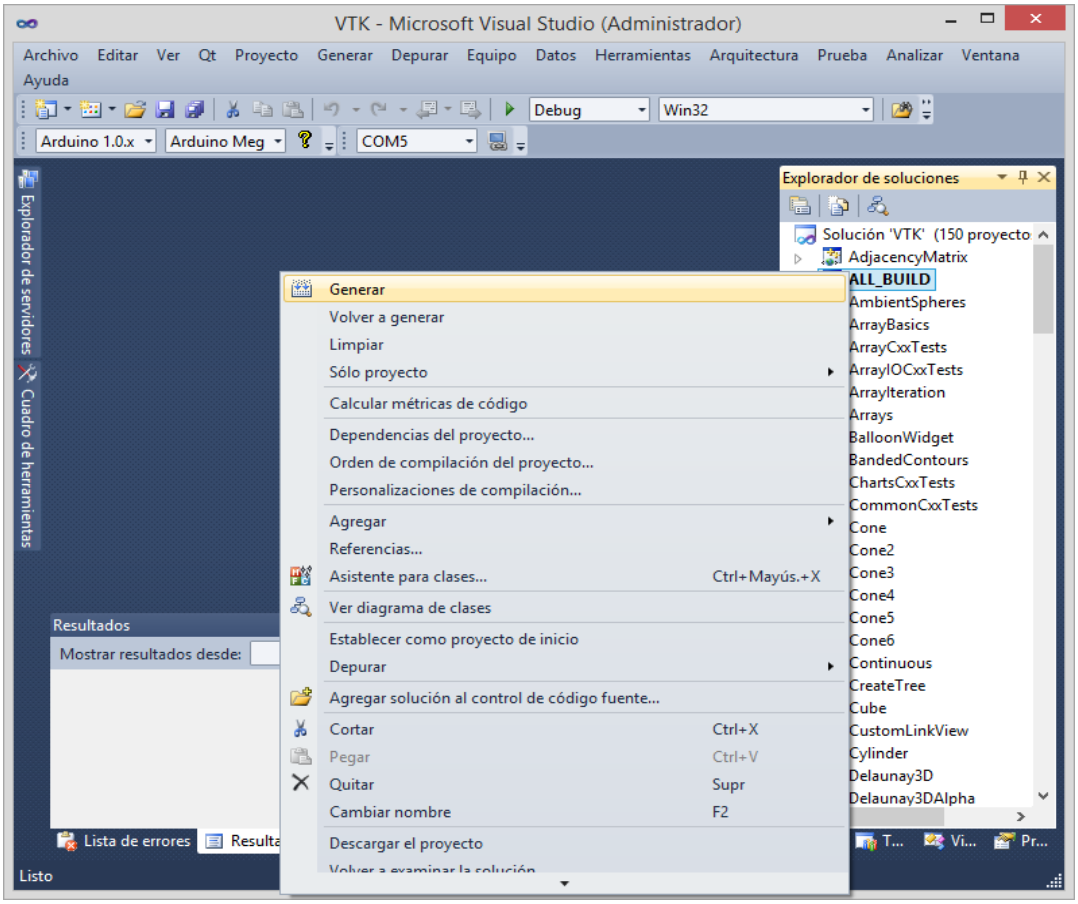

Figura D12. Compilación VTK en Visual studio

En la ventana inferior de Visual Studio se pueden ver los resultados de la compilación, para finalizar en el explorador de soluciones se escoge la opción ‘INSTALL’, damos clic derecho y damos clic en la opción ‘generar’.

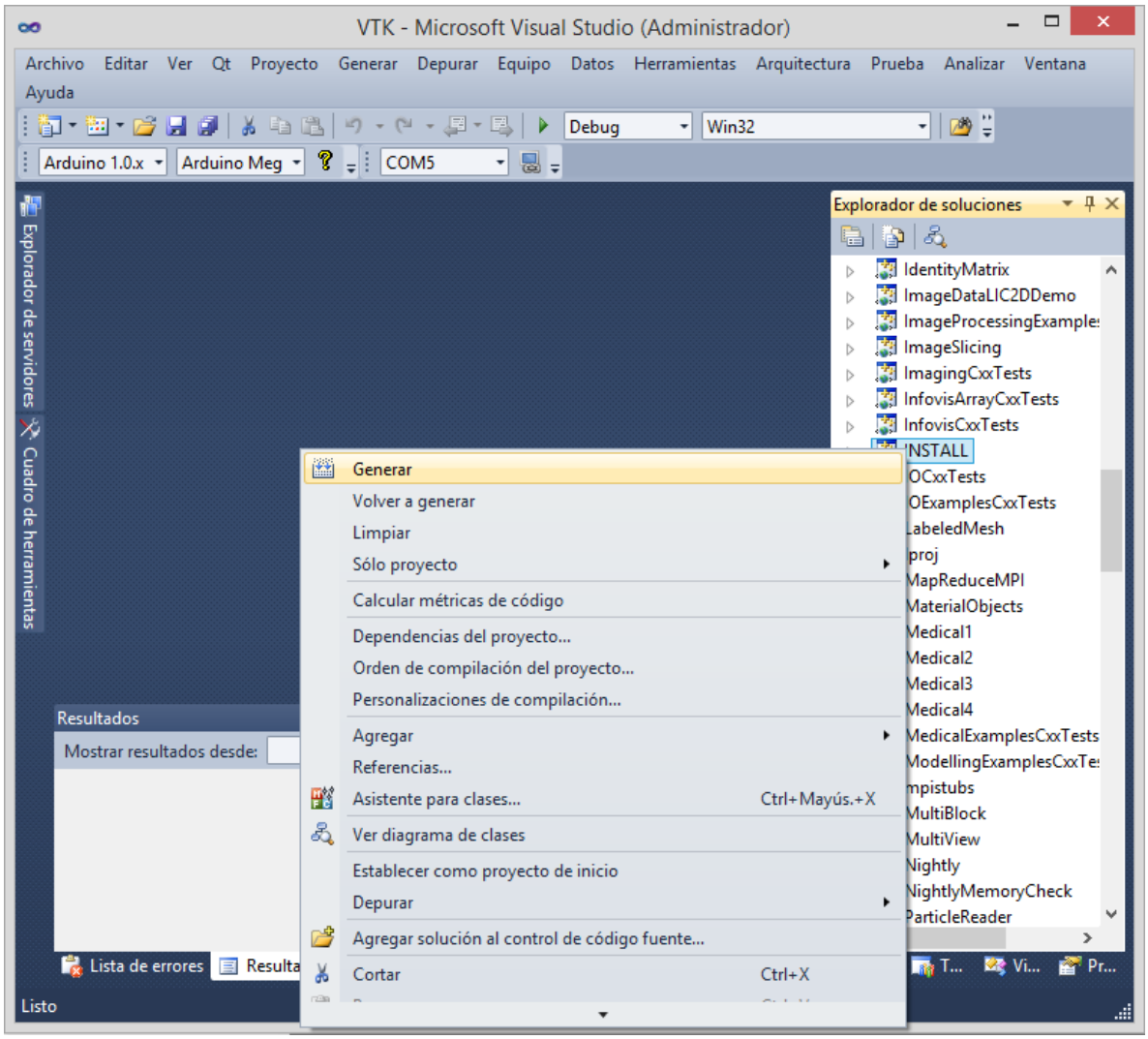

Figura D13. Compilación VTK en Visual Studio (INSTALL)

Para finalizar la configuración la compilación debe estar sin errores, una vez verificado la ventana de resultados se da por terminada la instalación de las librerías VTK, y se cierra la ventana de Visual Studio.