Anexos

A.I Clases

Por metodología, se definen siempre un constructor y un destructor, aunque en muchas ocasiones no realicen acción alguna. En los cuadros sólo se presenta la interfaz: las funciones no pertenecientes a ella, no se muestran. Los nombres de los parámetros o los tipos que se devuelven sólo aparecerán en el cuadro cuando sean importantes para la comprensión de la función.

Clases en Bridge Module (`./hero/ril/bridge/source/`)

CBridgeModCommunication

`CBridgeModCommunication(int id);`
`~CBridgeModCommunication( );`
 	
`Init( );`
 	
`ReceiveBridgeModuleMovementData(CBridgeModCriticalSection* );`
`ReceiveBridgeModuleControlData(CBridgeModCriticalSection* );`
`SendBridgeModuleState(CBridgeModCriticalSection* );`
`SendBridgeModuleDSPStatus(CBridgeModCriticalSection* );`
 	
`InitCommunications( );`

CBridgeModCriticalSection

`CBridgeModCriticalSection( );`
`~CBridgeModCriticalSection( );`
 	
`SetBridgeModDSPStatus(DSP_HERO_TELEMETRY* );`
`GetBridgeModDSPStatus(DSP_HERO_TELEMETRY* );`
`SetBridgeModuleState(ModuleState* );`
`GetBridgeModuleState(ModuleState* );`
`SetBridgeModControlData(ModuleControl* );`
`GetBridgeModControlData(ModuleControl* );`
`SetBridgeModMovementData(MovementData* );`
`GetBridgeModMovementData(MovementData* );`
`CheckIfNewMovementDataHaveArrived( );`
 	
`SetAckError(AckError* );`
`GetAckError(AckError* );`
`SetCommandMessageToDSPComm(MENSAJE* );`
`GetCommandMessageToDSPComm(MENSAJE* );`
`SetWPMessageToDSPComm(MENSAJE* );`
`GetWPMessageToDSPComm(MENSAJE* );`
 	
`SetDSPError(DSPError* );`
`GetDSPError(DSPError* );`
 	
`SetDSPFlagPeticionTxWP(DSPFlagPeticionTxWP* );`
`GetDSPFlagPeticionTxWP(DSPFlagPeticionTxWP* );`
`SetDSPAck(DSPAck* );`
`GetDSPAck(DSPAck* );`
 	
`SetMessageToSerialWriting(MENSAJE* );`
`GetMessageToSerialWriting(MENSAJE* );`

```
SetDSPTime(unsigned int *time);
GetDSPTime(unsigned int *time);

SetMovementCommandFunctionalityState(FUNCTIONALITY_STATE* );
GetMovementCommandFunctionalityState(FUNCTIONALITY_STATE* );
SetStopFncFlag(int *flag);
GetStopFncFlag(int *flag);
SetBlockStatus(bool *flag);
GetBlockStatus(bool *flag);

ClearWPMessagesToDSPCommList( );
ClearDSPErrorsToProcCola( );
```

Protocolo_DSP_PC

```
Protocolo_DSP_PC( );
~Protocolo_DSP_PC( );

procesa_caracter_recibido(char , ESTADO* , short int mascara);

empaqueta_mensaje_mascara(char* , short int mascara);
empaqueta_mensaje_activar_tx_estado(char* );
empaqueta_limpiar_codigo_de_error(char* );
empaqueta_activar_seguimiento(char* );
empaqueta_desactivar_seguimiento(char* );
empaqueta_invalidar_camino(char* );

empaqueta_escritura_en_puerto_16(char *mensaje, unsigned short puerto,
short valor);
empaqueta_escritura_en_puerto_32(char *mensaje, unsigned short puerto,
float valor);
empaqueta_lectura_en_puerto_16(char *mensaje, unsigned short puerto);
empaqueta_lectura_en_puerto_32(char *mensaje, unsigned short puerto);

empaqueta_datos_camino_geo(double latitud, double longitud,double
altura, char* );
```

PuertoSerie

```
PuertoSerie(char *puerto = DEFAULT_PORT, int speed = DEFAULT_SPEED);
~PuertoSerie();

init_puerto_serie(int baud = DEFAULT_SPEED);
close_puerto_serie( );

char leer_caracter_puerto_serie( );
escribir_caracter_puerto_serie(char );
enviar_cadena_puerto_serie(char* );
recibir_cadena_puerto_serie(unsigned char* , int length);

posicionar_principio_puerto_serie( );
```

Cparser
CParser(void); CParser(char *FileName); ~CParser( ); SetFile(char *FileName); ParseFile(CONFIG*);

template: Cola<T>

Cola( );
~Cola( );
 	
meter_en_cola(T*);
bool sacar_de_cola(T*);
 	
limpiar_cola( );

CBridgeModManager
CBridgeModManager( ); ~CBridgeModManager( ); InitManager(CBridgeModCriticalSection*); int SetModuleActionAndUpdateModuleState(CBridgeModCriticalSection*);

Clases en Status Module (./hero/ril/status/source/)

CStatusModCommunication
CStatusModCommunication(int *id*); ~CStatusModCommunication( ); Init( ); ReceiveStatusModuleDSPStatus(CStatusModCriticalSection*); SendStatusModuleHeroTelemetry(CStatusModCriticalSection*); InitCommunications( );

CStatusModCriticalSection

```
CStatusModCriticalSection( );
~CStatusModCriticalSection( );

SetStatusModDSPStatus(DSP_HERO_TELEMETRY* );
GetStatusModDSPStatus(DSP_HERO_TELEMETRY* );

SetStatusModHeroTelemetry(HERO_TELEMETRY* );
GetStatusModHeroTelemetry(HERO_TELEMETRY* );
```

CParser_HSMLog

```
CParser_HSMLog( );
CParser_HSMLog(char *FileName);
~CParser_HSMLog( );

SetFile(char *FileName);

ParseFile(LOGCONFIG* );
```

HSMLog

```
HSMLog(LOGCONFIG* , int id);
~HSMLog( );

WriteIn(DSP_HERO_TELEMETRY* );
```

Clases en DSP Simulator (./hero/DSP_simulator/source/)

PCComm

```
PCComm( );
~PCComm( );

codifica_estado( );
codifica_mensaje_control_de_flujo(int peticion_de_tx);
codifica_mensaje_de_error(int error_code);
codifica_mensaje_de_asentimiento(int codigo_comando,long int valor,
int tamano_valor);
int procesa_caracter_del_PC(char caracter);

GetMensajeToPC (MessageToPC* );
GetPCComando(PC_COMANDO* );
GetPCCaminoXYZ(PC_DATO_CAMINO_XYZ* );
GetPCCaminoGeo(PC_DATO_CAMINO_GEO* );

SetSimulatedStatus(ESTADO_HELICOPTERO* );
UpdateMask(int *mask);
```

CDSPSimulatorCriticalSection

```
CDSPSimulatorCriticalSection( );
~CDSPSimulatorCriticalSection( );

SetCommandMessageToDSP(PC_COMANDO* );
GetCommandMessageToDSP(PC_COMANDO* );
SetWPMessageToDSP(PC_DATO_CAMINO_GEO* );
GetWPMessageToDSP(PC_DATO_CAMINO_GEO* );

SetCharToPC(MessageToPC* );
GetCharToPC(MessageToPC* );

SetDSPSimulatedStatus(ESTADO_HELICOPTERO* );
GetDSPSimulatedStatus(ESTADO_HELICOPTERO* );
SetWP(PC_DATO_CAMINO_GEO* );
GetWP(PC_DATO_CAMINO_GEO* );
SetDSPError(DSPError* );
GetDSPError(DSPError* );
SetDSPFlagPeticionTxWP(DSPFlagPeticionTxWP* );
GetDSPFlagPeticionTxWP(DSPFlagPeticionTxWP* );
SetDSPAck(DSPAck* );
GetDSPAck(DSPAck* );

SetDSPTime(unsigned int *time);
GetDSPTime(unsigned int *time);

SetStateMask(int *mask);
GetStateMask(int *mask);

SetVelocidad(float *velocidad);
GetVelocidad(float *velocidad);

SetTakeOffMode(int *mode);
GetTakeOffMode(int *mode);

SetLandMode(int *mode);
GetLandMode(int *mode);

SetHoverFlag(bool *flag);
GetHoverFlag(bool *flag);

ClearWPMessagesToDSPCola( );
ClearWPCola( );
ClearDSPErrorsCola( );
```

DSPCommManager

```
DSPCommManager( );
~DSPCommManager( );

ReceiveAndDoWhatCommandSays( );

ReceiveWayPointIfThereIsOne( );

SendEstadoIfTxIsOn( );

SendErrorIfThereIsOne( );
```

HelicopterModel

```
HelicopterModel( );
~HelicopterModel( );

simstep(short spc, short spx, short spy, short sph, short sth);

GetSimulatorState(SimState* );
SetSimulatorState(SimState* );

GetXState(xState* );
SetXState(xState* );

drotxy(double x, double y, double a, double *xr, double *yr);
```

UAVSimulator

```
UAVSimulator(HomeParameters );
UAVSimulator( );
~UAVSimulator( );

SetHomeParameters(HomeParameters* );

ReceiveMovementData( );

SimulatedDynamic(bool hover);

SendSensorStatus( );

bool HaveWeArrivedToLastWaypoint( );

ForDebugging( );
```

UAVRealSimulator

```
UAVRealSimulator(HomeParameters );
UAVRealSimulator( );
~UAVRealSimulator( );

SetHomeParameters(HomeParameters* );

ReceiveMovementData( );

SimulatedDynamic(bool hover);

SendSensorStatus( );

bool HaveWeArrivedToLastWaypoint( );

ForDebugging( );
```

A.II Ecuaciones en el Espacio de Estados y linealización

$$x_{13}^{k+1} = x_{13}^{k} + k_1 \cdot u_5^k - k_2 \cdot \left(\frac{x_{13}^k}{E_1} \right)^2 u_1^k = f_{13}\left(x^k, u^k\right)$$

$$x_{12}^{k+1} = x_{12}^{k} + \left[\frac{f_{13}\left(x^k, u^k\right)}{E_6} \frac{u_1^k - E_7}{k_3 \cdot \max\left(u_1\right)} + \frac{u_4^k - E_8}{\max\left(u_4\right)} \right] E_9 \cdot W_{360} \cdot T = f_{12}\left(x^k, u^k\right)$$

$$x_9^{k+1} = x_9^k + f_{12}\left(x^k, u^k\right) \cdot T = f_9\left(x^k, u^k\right)$$

$$x_8^{k+1} = x_8^k + \frac{E_{4y}}{E_{5y}} u_3^k \cdot T = f_8\left(x^k, u^k\right)$$

$$x_7^{k+1} = x_7^k + \frac{E_{4x}}{E_{5x}} u_2^k \cdot T = f_7\left(x^k, u^k\right)$$

$$x_6^{k+1} = x_6^k + \frac{u_1^k}{\max\left(u_1\right)} \cdot E_3 \cdot g\,T \cdot \frac{f_{13}\left(x^k, u^k\right)}{E_2} - g\,T = f_6\left(x^k, u^k\right)$$

$$x_5^{k+1} = x_5^k + \left\{ \frac{2\pi\, g}{W_{360}} g_8\left(x^k, u^k\right) \cdot \sin\left(f_9\left(x^k, u^k\right) \frac{2\pi}{W_{360}} \right) - \right.$$
$$\left. - \left[\frac{2\pi\, g}{W_{360}} g_7\left(x^k, u^k\right) + \frac{u_4^k - k_4 \max\left(u_4\right)}{\max\left(u_4\right)} \frac{g}{E_{10}} \right] \cdot \cos\left(f_9\left(x^k, u^k\right) \frac{2\pi}{W_{360}} \right) \right\} T = f_5\left(x^k, u^k\right)$$

$$x_4^{k+1} = x_4^k + \left\{ \frac{2\pi\, g}{W_{360}} g_8\left(x^k, u^k\right) \cdot \cos\left(f_9\left(x^k, u^k\right) \frac{2\pi}{W_{360}} \right) + \right.$$
$$\left. + \left[\frac{2\pi\, g}{W_{360}} g_7\left(x^k, u^k\right) + \frac{u_4^k - k_4 \max\left(u_4\right)}{\max\left(u_4\right)} \frac{g}{E_{10}} \right] \cdot \sin\left(f_9\left(x^k, u^k\right) \frac{2\pi}{W_{360}} \right) \right\} T = f_4\left(x^k, u^k\right)$$

$$x_3^{k+1} = x_3^k + f_6\left(x^k, u^k\right) \cdot T = f_3\left(x^k, u^k\right)$$

$$x_2^{k+1} = x_2^k + f_5\left(x^k, u^k\right) \cdot T = f_2\left(x^k, u^k\right)$$

$$x_1^{k+1} = x_1^k + f_4\left(x^k, u^k\right) \cdot T = f_1\left(x^k, u^k\right)$$

Ecs II.1.1 Ecuaciones del Sistema: *f(x,u)*

$$y_1^k = f_1\left(x^k, u^k\right) = g_1\left(x^k, u^k\right)$$

$$y_2^k = f_2\left(x^k, u^k\right) = g_2\left(x^k, u^k\right)$$

$$y_3^k = f_3\left(x^k, u^k\right) = g_3\left(x^k, u^k\right)$$

$$y_4^k = f_4\left(x^k, u^k\right) = g_4\left(x^k, u^k\right)$$

$$y_5^k = f_5\left(x^k, u^k\right) = g_5\left(x^k, u^k\right)$$

$$y_6^k = f_6\left(x^k, u^k\right) = g_6\left(x^k, u^k\right)$$

$$y_7^k = f_8\left(x^k, u^k\right) \cdot \sin\left(f_{12}\left(x^k, u^k\right) T \frac{2\pi}{W_{360}} \right) + f_7\left(x^k, u^k\right) \cdot \cos\left(f_{12}\left(x^k, u^k\right) T \frac{2\pi}{W_{360}} \right) = g_7\left(x^k, u^k\right)$$

$$y_8^k = f_8\left(x^k, u^k\right) \cdot \cos\left(f_{12}\left(x^k, u^k\right) T \frac{2\pi}{W_{360}} \right) - f_7\left(x^k, u^k\right) \cdot \sin\left(f_{12}\left(x^k, u^k\right) T \frac{2\pi}{W_{360}} \right) = g_8\left(x^k, u^k\right)$$

$$y_9^k = f_9\left(x^k, u^k\right) = g_9\left(x^k, u^k\right)$$

$$y_{10}^k = \frac{E_{4x}}{E_{5x}} u_2^k = g_{10}\left(x^k, u^k\right)$$

$$y_{11}^k = \frac{E_{4y}}{E_{5y}} u_3^k = g_{11}\left(x^k, u^k\right)$$

$$y_{12}^k = f_{12}\left(x^k, u^k\right) = g_{12}\left(x^k, u^k\right)$$

$$y_{13}^k = f_{13}\left(x^k, u^k\right) = g_{13}\left(x^k, u^k\right)$$

Ecs II.1.2 Ecuaciones del Sistema: *g(x,u)*

$$a_x^{/}(x_k,u_k)=y_8^k\cdot\frac{2\pi\,g}{W_{360}}=\frac{2\pi\,g}{W_{360}}\,g_8\left(x^k,u^k\right)$$

$$a_y^{/}(x_k,u_k)=-y_7^k\cdot\frac{2\pi\,g}{W_{360}}-\frac{u_4^k-k_4\max(u_4)}{\max(u_4)}\frac{g}{E_{10}}=-\frac{2\pi\,g}{W_{360}}\,g_7\left(x^k,u^k\right)-\frac{u_4^k-k_4\max(u_4)}{\max(u_4)}\frac{g}{E_{10}}$$

$$a_x(x_k,u_k)=a_x^{/}(x_k,u_k)\cdot\cos\left(f_9\left(x^k,u^k\right)\frac{2\pi}{W_{360}}\right)-a_y^{/}(x_k,u_k)\cdot\sin\left(f_9\left(x^k,u^k\right)\frac{2\pi}{W_{360}}\right)=$$

$$=\frac{2\pi\,g}{W_{360}}\,g_8\left(x^k,u^k\right)\cdot\cos\left(f_9\left(x^k,u^k\right)\frac{2\pi}{W_{360}}\right)+$$

$$+\left[\frac{2\pi\,g}{W_{360}}\,g_7\left(x^k,u^k\right)+\frac{u_4^k-k_4\max(u_4)}{\max(u_4)}\frac{g}{E_{10}}\right]\cdot\sin\left(f_9\left(x^k,u^k\right)\frac{2\pi}{W_{360}}\right)$$

$$a_y(x_k,u_k)=a_x^{/}(x_k,u_k)\cdot\sin\left(f_9\left(x^k,u^k\right)\frac{2\pi}{W_{360}}\right)+a_y^{/}(x_k,u_k)\cdot\cos\left(f_9\left(x^k,u^k\right)\frac{2\pi}{W_{360}}\right)=$$

$$=\frac{2\pi\,g}{W_{360}}\,g_8\left(x^k,u^k\right)\cdot\sin\left(f_9\left(x^k,u^k\right)\frac{2\pi}{W_{360}}\right)-$$

$$-\left[\frac{2\pi\,g}{W_{360}}\,g_7\left(x^k,u^k\right)+\frac{u_4^k-k_4\max(u_4)}{\max(u_4)}\frac{g}{E_{10}}\right]\cdot\cos\left(f_9\left(x^k,u^k\right)\frac{2\pi}{W_{360}}\right)$$

Ecs II.1.3 Ecuaciones del Sistema: aceleraciones

$$\overbrace{\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad}^{k=h}$$

$$x_{13}^{k+1} = x_{13}^{k} \quad \Rightarrow \quad k_1 \cdot u_5^h - k_2 \cdot \left(\frac{x_{13}^h}{E_1} \right)^2 u_1^h = 0$$

$$x_{12}^{k+1} = x_{12}^{k} \quad \Rightarrow \quad \begin{cases} u_1^h = E_7 \\ u_4^h = E_8 \end{cases}$$

$$x_9^{k+1} = x_9^{k} \quad \Rightarrow \quad x_{12}^h = 0$$

$$x_8^{k+1} = x_8^{k} \quad \Rightarrow \quad u_3^h = 0$$

$$x_7^{k+1} = x_7^{k} \quad \Rightarrow \quad u_2^h = 0$$

$$x_6^{k+1} = x_6^{k} \quad \Rightarrow \quad \frac{u_1^h}{\max(u_1)} \cdot E_3 \cdot \frac{x_{13}^h}{E_2} = 1$$

$$\left.\begin{matrix} x_5^{k+1} = x_5^{k} \\ x_4^{k+1} = x_4^{k} \end{matrix}\right\} \quad \Rightarrow \quad \begin{cases} y_7^h = 0 \\ y_8^h = 0 \end{cases}$$

$$x_3^{k+1} = x_3^{k} \quad \Rightarrow \quad x_6^h = 0$$

$$x_2^{k+1} = x_2^{k} \quad \Rightarrow \quad x_5^h = 0$$

$$x_1^{k+1} = x_1^{k} \quad \Rightarrow \quad x_4^h = 0$$

Ecs II.2.1 Ecuaciones del *hover* matemático: *x*

$$\left.\begin{matrix} y_7^h = 0 \\ y_8^h = 0 \end{matrix}\right\} \quad \Rightarrow \quad \begin{cases} x_7^h = 0 \\ x_8^h = 0 \end{cases}$$

Ecs II.2.2 Ecuaciones del *hover* matamático: *y*

$$\left.\begin{matrix} a_x = 0 \\ a_y = 0 \end{matrix}\right\} \quad \Rightarrow \quad \left\{\begin{matrix} a_x^{/} = 0 \\ a_y^{/} = 0 \end{matrix}\right\} \quad \Rightarrow \quad \begin{cases} y_8^h = 0 \quad \text{(como ya sabíamos)} \\ u_4^h - k_4 \max(u_4) = 0 \end{cases}$$

Ecs II.2.3 Ecuaciones del *hover* matamático: aceleraciones

$$\left.\frac{\partial f_{13}}{\partial x_{13}^{k}}\right|_{h} = 1 - 2\,k_2\,\frac{x_{13}^{h}}{(E_1)^2}\,u_1^{h} = \left.\frac{\partial g_{13}}{\partial x_{13}^{k}}\right|_{h}$$

$$\left.\frac{\partial f_{13}}{\partial u_{1}^{k}}\right|_{h} = -k_2\left(\frac{x_{13}^{h}}{E_1}\right)^2 = \left.\frac{\partial g_{13}}{\partial u_{1}^{k}}\right|_{h}$$

$$\left.\frac{\partial f_{13}}{\partial u_{5}^{k}}\right|_{h} = k_1 = \left.\frac{\partial g_{13}}{\partial u_{5}^{k}}\right|_{h}$$

$$\left.\frac{\partial f_{12}}{\partial x_{12}^{k}}\right|_{h} = 1 = \left.\frac{\partial g_{12}}{\partial x_{12}^{k}}\right|_{h}$$

$$\left.\frac{\partial f_{12}}{\partial x_{13}^{k}}\right|_{h} = E_9 \cdot W_{360} \cdot T\,\frac{u_1^{h} - E_7}{k_3 \cdot \max(u_1)}\left.\frac{\partial f_{13}}{\partial x_{13}^{k}}\right|_{h} \cdot \frac{1}{E_6} = \left.\frac{\partial g_{12}}{\partial x_{13}^{k}}\right|_{h}$$

$$\left.\frac{\partial f_{12}}{\partial u_{1}^{k}}\right|_{h} = \left[\frac{1}{E_6}\,\frac{u_1^{h} - E_7}{k_3 \cdot \max(u_1)}\left.\frac{\partial f_{13}}{\partial u_{1}^{k}}\right|_{h} + \frac{f_{13}\left(x^{h}, u^{h}\right)}{E_6}\,\frac{1}{k_3 \cdot \max(u_1)}\right] \cdot E_9 \cdot W_{360} \cdot T = \left.\frac{\partial g_{12}}{\partial u_{1}^{k}}\right|_{h}$$

$$\left.\frac{\partial f_{12}}{\partial u_{4}^{k}}\right|_{h} = \frac{1}{\max(u_4)}\,E_9 \cdot W_{360} \cdot T = \left.\frac{\partial g_{12}}{\partial u_{4}^{k}}\right|_{h}$$

$$\left.\frac{\partial f_{12}}{\partial u_{5}^{k}}\right|_{h} = E_9 \cdot W_{360} \cdot T\,\frac{u_1^{h} - E_7}{k_3 \cdot \max(u_1)}\left.\frac{\partial f_{13}}{\partial u_{5}^{k}}\right|_{h} \cdot \frac{1}{E_6} = \left.\frac{\partial g_{12}}{\partial u_{5}^{k}}\right|_{h}$$

$$\left.\frac{\partial f_9}{\partial x_9^k}\right|_h = 1 = \left.\frac{\partial g_9}{\partial x_9^k}\right|_h$$

$$\left.\frac{\partial f_9}{\partial x_{12}^k}\right|_h = T = \left.\frac{\partial g_9}{\partial x_{12}^k}\right|_h$$

$$\left.\frac{\partial f_9}{\partial x_{13}^k}\right|_h = T\left.\frac{\partial f_{12}}{\partial x_{13}^k}\right|_h = \left.\frac{\partial g_9}{\partial x_{13}^k}\right|_h$$

$$\left.\frac{\partial f_9}{\partial u_1^k}\right|_h = T\left.\frac{\partial f_{12}}{\partial u_1^k}\right|_h = \left.\frac{\partial g_9}{\partial u_1^k}\right|_h$$

$$\left.\frac{\partial f_9}{\partial u_4^k}\right|_h = T\left.\frac{\partial f_{12}}{\partial u_4^k}\right|_h = \left.\frac{\partial g_9}{\partial u_4^k}\right|_h$$

$$\left.\frac{\partial f_9}{\partial u_5^k}\right|_h = T\left.\frac{\partial f_{12}}{\partial u_5^k}\right|_h = \left.\frac{\partial g_9}{\partial u_5^k}\right|_h$$

$$\left.\frac{\partial f_8}{\partial x_8^k}\right|_h = 1$$

$$\left.\frac{\partial f_8}{\partial u_3^k}\right|_h = \frac{E_{4y}}{E_{5y}} \cdot T$$

$$\left.\frac{\partial f_7}{\partial x_7^k}\right|_h = 1$$

$$\left.\frac{\partial f_7}{\partial u_2^k}\right|_h = \frac{E_{4x}}{E_{5x}} \cdot T$$

$$\left.\frac{\partial f_6}{\partial x_6^k}\right|_h = 1 = \left.\frac{\partial g_6}{\partial x_6^k}\right|_h$$

$$\left.\frac{\partial f_6}{\partial x_{13}^k}\right|_h = \frac{u_1^h}{\max(u_1)}\frac{E_3 \cdot g\,T}{E_2}\left.\frac{\partial f_{13}}{\partial x_{13}^k}\right|_h = \left.\frac{\partial g_6}{\partial x_{13}^k}\right|_h$$

$$\left.\frac{\partial f_6}{\partial u_1^k}\right|_h = \frac{E_3}{\max(u_1)}gT\frac{f_{13}\left(x^h,u^h\right)}{E_2} + \frac{u_1^h}{\max(u_1)}\frac{E_3 \cdot g\,T}{E_2}\left.\frac{\partial f_{13}}{\partial u_1^k}\right|_h = \left.\frac{\partial g_6}{\partial u_1^k}\right|_h$$

$$\left.\frac{\partial f_6}{\partial u_5^k}\right|_h = \frac{u_1^h}{\max(u_1)}\frac{E_3 \cdot g\,T}{E_2}\left.\frac{\partial f_{13}}{\partial u_5^k}\right|_h = \left.\frac{\partial g_6}{\partial u_5^k}\right|_h$$

$$\left.\frac{\partial f_5}{\partial x_5^k}\right|_h = 1$$

$$\left.\frac{\partial f_5}{\partial x_7^k}\right|_h = T\left[\frac{2\pi\, g}{W_{360}}\left.\frac{\partial g_8}{\partial x_7^k}\right|_h \cdot \sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right) - \frac{2\pi\, g}{W_{360}}\cdot\left.\frac{\partial g_7}{\partial x_7^k}\right|_h \cdot \cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\right]$$

$$\left.\frac{\partial f_5}{\partial x_8^k}\right|_h = T\left[\frac{2\pi\, g}{W_{360}}\left.\frac{\partial g_8}{\partial x_8^k}\right|_h \cdot \sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right) - \frac{2\pi\, g}{W_{360}}\cdot\left.\frac{\partial g_7}{\partial x_8^k}\right|_h \cdot \cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\right]$$

$$\left.\frac{\partial f_5}{\partial x_9^k}\right|_h = T\left[\frac{2\pi\, g}{W_{360}} g_8\left(x^h,u^h\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}} + \right.$$
$$\left. + \left(\frac{2\pi\, g}{W_{360}} g_7\left(x^h,u^h\right) + \frac{u_4^h - k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\right]$$

$$\left.\frac{\partial f_5}{\partial x_{12}^k}\right|_h = T\left[\frac{2\pi\, g}{W_{360}}\left.\frac{\partial g_8}{\partial x_{12}^k}\right|_h \cdot \sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right) + \right.$$
$$+ \frac{2\pi\, g}{W_{360}} g_8\left(x^h,u^h\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\cdot\left.\frac{\partial f_9}{\partial x_{12}^k}\right|_h - \frac{2\pi\, g}{W_{360}}\cdot\left.\frac{\partial g_7}{\partial x_{12}^k}\right|_h \cdot \cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right) +$$
$$\left. + \left(\frac{2\pi\, g}{W_{360}} g_7\left(x^h,u^h\right) + \frac{u_4^h - k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial x_{12}^k}\right|_h\right]$$

$$\left.\frac{\partial f_5}{\partial x_{13}^k}\right|_h = T\left[\frac{2\pi\, g}{W_{360}}\left.\frac{\partial g_8}{\partial x_{13}^k}\right|_h \cdot \sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right) + \right.$$
$$+ \frac{2\pi\, g}{W_{360}} g_8\left(x^h,u^h\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\cdot\left.\frac{\partial f_9}{\partial x_{13}^k}\right|_h - \frac{2\pi\, g}{W_{360}}\cdot\left.\frac{\partial g_7}{\partial x_{13}^k}\right|_h \cdot \cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right) +$$
$$\left. + \left(\frac{2\pi\, g}{W_{360}} g_7\left(x^h,u^h\right) + \frac{u_4^h - k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial x_{13}^k}\right|_h\right]$$

$$\left.\frac{\partial g_5}{\partial x_i^k}\right|_h = \left.\frac{\partial f_5}{\partial x_i^k}\right|_h \qquad \forall i$$

$$\left.\frac{\partial f_5}{\partial u_1^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial u_1^k}\right|_h \cdot \sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+\right.$$
$$+\frac{2\pi\, g}{W_{360}}\, g_8\left(x^h,u^h\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\cdot\left.\frac{\partial f_9}{\partial u_1^k}\right|_h - \left.\frac{2\pi\, g}{W_{360}}\cdot\frac{\partial g_7}{\partial u_1^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+$$
$$\left.+\left(\frac{2\pi\, g}{W_{360}}\, g_7\left(x^h,u^h\right)+\frac{u_4^h-k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial u_1^k}\right|_h\right]$$

$$\left.\frac{\partial f_5}{\partial u_2^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial u_2^k}\right|_h \cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)-\left.\frac{2\pi\, g}{W_{360}}\cdot\frac{\partial g_7}{\partial u_2^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\right]$$

$$\left.\frac{\partial f_5}{\partial u_3^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial u_3^k}\right|_h \cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)-\left.\frac{2\pi\, g}{W_{360}}\cdot\frac{\partial g_7}{\partial u_3^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\right]$$

$$\left.\frac{\partial f_5}{\partial u_4^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial u_4^k}\right|_h \cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+\right.$$
$$+\frac{2\pi\, g}{W_{360}}\, g_8\left(x^h,u^h\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\cdot\left.\frac{\partial f_9}{\partial u_4^k}\right|_h -$$
$$-\left(\left.\frac{2\pi\, g}{W_{360}}\cdot\frac{\partial g_7}{\partial u_4^k}\right|_h +\frac{g}{k_4\cdot\max\left(u_4\right)E_{10}}\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+$$
$$\left.+\left(\frac{2\pi\, g}{W_{360}}\, g_7\left(x^h,u^h\right)+\frac{u_4^h-k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial u_4^k}\right|_h\right]$$

$$\left.\frac{\partial f_5}{\partial u_5^k}\right|_h = T\left[\frac{2\pi\, g}{W_{360}}\, g_8\left(x^h,u^h\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial u_5^k}\right|_h +\right.$$
$$\left.+\left(\frac{2\pi\, g}{W_{360}}\, g_7\left(x^h,u^h\right)+\frac{u_4^h-k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial u_5^k}\right|_h\right]$$

$$\left.\frac{\partial g_5}{\partial u_i^k}\right|_h = \left.\frac{\partial f_5}{\partial u_i^k}\right|_h \qquad \forall i$$

$$\left.\frac{\partial f_4}{\partial x_4^k}\right|_h = 1$$

$$\left.\frac{\partial f_4}{\partial x_7^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial x_7^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+\frac{2\pi\, g}{W_{360}}\cdot\left.\frac{\partial g_7}{\partial x_7^k}\right|_h \cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\right]$$

$$\left.\frac{\partial f_4}{\partial x_8^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial x_8^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+\frac{2\pi\, g}{W_{360}}\cdot\left.\frac{\partial g_7}{\partial x_8^k}\right|_h \cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\right]$$

$$\left.\frac{\partial f_4}{\partial x_9^k}\right|_h = T\left[-\frac{2\pi\, g}{W_{360}}g_8\left(x^h,u^h\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}+\right.$$
$$\left.+\left(\frac{2\pi\, g}{W_{360}}g_7\left(x^h,u^h\right)+\frac{u_4^h-k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\right]$$

$$\left.\frac{\partial f_4}{\partial x_{12}^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial x_{12}^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)-\right.$$
$$-\frac{2\pi\, g}{W_{360}}g_8\left(x^h,u^h\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\cdot\left.\frac{\partial f_9}{\partial x_{12}^k}\right|_h+\left.\frac{2\pi\, g}{W_{360}}\cdot\frac{\partial g_7}{\partial x_{12}^k}\right|_h \cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+$$
$$\left.+\left(\frac{2\pi\, g}{W_{360}}g_7\left(x^h,u^h\right)+\frac{u_4^h-k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial x_{12}^k}\right|_h\right]$$

$$\left.\frac{\partial f_4}{\partial x_{13}^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial x_{13}^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)-\right.$$
$$-\frac{2\pi\, g}{W_{360}}g_8\left(x^h,u^h\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\cdot\left.\frac{\partial f_9}{\partial x_{13}^k}\right|_h+\left.\frac{2\pi\, g}{W_{360}}\cdot\frac{\partial g_7}{\partial x_{13}^k}\right|_h \cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+$$
$$\left.+\left(\frac{2\pi\, g}{W_{360}}g_7\left(x^h,u^h\right)+\frac{u_4^h-k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial x_{13}^k}\right|_h\right]$$

$$\left.\frac{\partial g_4}{\partial x_i^k}\right|_h = \left.\frac{\partial f_4}{\partial x_i^k}\right|_h \qquad \forall i$$

$$\left.\frac{\partial f_4}{\partial u_1^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial u_1^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)-\right.$$
$$-\frac{2\pi\, g}{W_{360}}\,g_8\left(x^h,u^h\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\cdot\left.\frac{\partial f_9}{\partial u_1^k}\right|_h+\left.\frac{2\pi\, g}{W_{360}}\cdot\frac{\partial g_7}{\partial u_1^k}\right|_h\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+$$
$$\left.+\left(\frac{2\pi\, g}{W_{360}}\,g_7\left(x^h,u^h\right)+\frac{u_4^h-k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial u_1^k}\right|_h\right]$$

$$\left.\frac{\partial f_4}{\partial u_2^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial u_2^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+\left.\frac{2\pi\, g}{W_{360}}\cdot\frac{\partial g_7}{\partial u_2^k}\right|_h\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\right]$$

$$\left.\frac{\partial f_4}{\partial u_3^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial u_3^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+\left.\frac{2\pi\, g}{W_{360}}\cdot\frac{\partial g_7}{\partial u_3^k}\right|_h\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\right]$$

$$\left.\frac{\partial f_4}{\partial u_4^k}\right|_h = T\left[\left.\frac{2\pi\, g}{W_{360}}\frac{\partial g_8}{\partial u_4^k}\right|_h \cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)-\right.$$
$$-\frac{2\pi\, g}{W_{360}}\,g_8\left(x^h,u^h\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\cdot\left.\frac{\partial f_9}{\partial u_4^k}\right|_h+$$
$$+\left(\left.\frac{2\pi\, g}{W_{360}}\cdot\frac{\partial g_7}{\partial u_4^k}\right|_h+\frac{g}{k_4\cdot\max\left(u_4\right)E_{10}}\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)+$$
$$\left.+\left(\frac{2\pi\, g}{W_{360}}\,g_7\left(x^h,u^h\right)+\frac{u_4^h-k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial u_4^k}\right|_h\right]$$

$$\left.\frac{\partial f_4}{\partial u_5^k}\right|_h = T\left[-\frac{2\pi\, g}{W_{360}}\,g_8\left(x^h,u^h\right)\cdot\sin\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial u_5^k}\right|_h+\right.$$
$$\left.+\left(\frac{2\pi\, g}{W_{360}}\,g_7\left(x^h,u^h\right)+\frac{u_4^h-k_4\max\left(u_4\right)}{\max\left(u_4\right)}\frac{g}{E_{10}}\right)\cdot\cos\left(f_9\left(x^h,u^h\right)\frac{2\pi}{W_{360}}\right)\frac{2\pi}{W_{360}}\left.\frac{\partial f_9}{\partial u_5^k}\right|_h\right]$$

$$\left.\frac{\partial g_4}{\partial u_i^k}\right|_h = \left.\frac{\partial f_4}{\partial u_i^k}\right|_h \qquad \forall i$$

$$\left.\frac{\partial f_3}{\partial x_3^k}\right|_h = 1 = \left.\frac{\partial g_3}{\partial x_3^k}\right|_h$$

$$\left.\frac{\partial f_3}{\partial x_6^k}\right|_h = T = \left.\frac{\partial g_3}{\partial x_6^k}\right|_h$$

$$\left.\frac{\partial f_3}{\partial x_{13}^k}\right|_h = T\left.\frac{\partial f_6}{\partial x_{13}^k}\right|_h = \left.\frac{\partial g_3}{\partial x_{13}^k}\right|_h$$

$$\left.\frac{\partial f_3}{\partial u_1^k}\right|_h = T\left.\frac{\partial f_6}{\partial u_1^k}\right|_h = \left.\frac{\partial g_3}{\partial u_1^k}\right|_h$$

$$\left.\frac{\partial f_3}{\partial u_5^k}\right|_h = T\left.\frac{\partial f_6}{\partial u_5^k}\right|_h = \left.\frac{\partial g_3}{\partial u_5^k}\right|_h$$

$$\left.\frac{\partial f_2}{\partial x_2^k}\right|_h = 1 = \left.\frac{\partial g_2}{\partial x_1^k}\right|_h$$

$$\left.\frac{\partial f_2}{\partial x_5^k}\right|_h = T = \left.\frac{\partial g_2}{\partial x_5^k}\right|_h$$

$$\left.\frac{\partial f_2}{\partial x_7^k}\right|_h = T\left.\frac{\partial f_5}{\partial x_7^k}\right|_h = \left.\frac{\partial g_2}{\partial x_7^k}\right|_h$$

$$\left.\frac{\partial f_2}{\partial x_8^k}\right|_h = T\left.\frac{\partial f_5}{\partial x_8^k}\right|_h = \left.\frac{\partial g_2}{\partial x_8^k}\right|_h$$

$$\left.\frac{\partial f_2}{\partial x_9^k}\right|_h = T\left.\frac{\partial f_5}{\partial x_9^k}\right|_h = \left.\frac{\partial g_2}{\partial x_9^k}\right|_h$$

$$\left.\frac{\partial f_2}{\partial x_{12}^k}\right|_h = T\left.\frac{\partial f_5}{\partial x_{12}^k}\right|_h = \left.\frac{\partial g_2}{\partial x_{12}^k}\right|_h$$

$$\left.\frac{\partial f_2}{\partial x_{13}^k}\right|_h = T\left.\frac{\partial f_5}{\partial x_{13}^k}\right|_h = \left.\frac{\partial g_2}{\partial x_{13}^k}\right|_h$$

$$\left.\frac{\partial f_2}{\partial u_i^k}\right|_h = T\left.\frac{\partial f_5}{\partial u_i^k}\right|_h = \left.\frac{\partial g_2}{\partial u_i^k}\right|_h \qquad \forall i$$

$$\left.\frac{\partial f_1}{\partial x_1^k}\right|_h = 1 = \left.\frac{\partial g_1}{\partial x_1^k}\right|_h$$

$$\left.\frac{\partial f_1}{\partial x_4^k}\right|_h = T = \left.\frac{\partial g_1}{\partial x_4^k}\right|_h$$

$$\left.\frac{\partial f_1}{\partial x_7^k}\right|_h = T\left.\frac{\partial f_4}{\partial x_7^k}\right|_h = \left.\frac{\partial g_1}{\partial x_7^k}\right|_h$$

$$\left.\frac{\partial f_1}{\partial x_8^k}\right|_h = T\left.\frac{\partial f_4}{\partial x_8^k}\right|_h = \left.\frac{\partial g_1}{\partial x_8^k}\right|_h$$

$$\left.\frac{\partial f_1}{\partial x_9^k}\right|_h = T\left.\frac{\partial f_4}{\partial x_9^k}\right|_h = \left.\frac{\partial g_1}{\partial x_9^k}\right|_h$$

$$\left.\frac{\partial f_1}{\partial x_{12}^k}\right|_h = T\left.\frac{\partial f_4}{\partial x_{12}^k}\right|_h = \left.\frac{\partial g_1}{\partial x_{12}^k}\right|_h$$

$$\left.\frac{\partial f_1}{\partial x_{13}^k}\right|_h = T\left.\frac{\partial f_4}{\partial x_{13}^k}\right|_h = \left.\frac{\partial g_1}{\partial x_{13}^k}\right|_h$$

$$\left.\frac{\partial f_1}{\partial u_i^k}\right|_h = T\left.\frac{\partial f_4}{\partial u_i^k}\right|_h = \left.\frac{\partial g_1}{\partial u_i^k}\right|_h \quad \forall i$$

$$\left.\frac{\partial g_7}{\partial x_7^k}\right|_h = \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right)$$

$$\left.\frac{\partial g_7}{\partial x_8^k}\right|_h = \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right)$$

$$\left.\frac{\partial g_7}{\partial x_{12}^k}\right|_h = f_8\left(x^h, u^h\right) \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} -$$
$$- f_7\left(x^h, u^h\right) \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}}$$

$$\left.\frac{\partial g_7}{\partial x_{13}^k}\right|_h = f_8\left(x^h, u^h\right) \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial x_{13}^k}\right|_h -$$
$$- f_7\left(x^h, u^h\right) \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial x_{13}^k}\right|_h$$

$$\left.\frac{\partial g_7}{\partial u_1^k}\right|_h = f_8\left(x^h, u^h\right) \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial u_1^k}\right|_h -$$
$$- f_7\left(x^h, u^h\right) \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial u_1^k}\right|_h$$

$$\left.\frac{\partial g_7}{\partial u_2^k}\right|_h = \left.\frac{\partial f_7}{\partial u_2^k}\right|_h \cdot \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right)$$

$$\left.\frac{\partial g_7}{\partial u_3^k}\right|_h = \left.\frac{\partial f_8}{\partial u_3^k}\right|_h \cdot \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right)$$

$$\left.\frac{\partial g_7}{\partial u_4^k}\right|_h = f_8\left(x^h, u^h\right) \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial u_4^k}\right|_h -$$
$$- f_7\left(x^h, u^h\right) \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial u_4^k}\right|_h$$

$$\left.\frac{\partial g_8}{\partial x_7^k}\right|_h = -\sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right)$$

$$\left.\frac{\partial g_8}{\partial x_8^k}\right|_h = \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right)$$

$$\left.\frac{\partial g_8}{\partial x_{12}^k}\right|_h = -f_8\left(x^h, u^h\right) \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} -$$
$$- f_7\left(x^h, u^h\right) \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}}$$

$$\left.\frac{\partial g_8}{\partial x_{13}^k}\right|_h = -f_8\left(x^h, u^h\right) \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial x_{13}^k}\right|_h -$$
$$- f_7\left(x^h, u^h\right) \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial x_{13}^k}\right|_h$$

$$\left.\frac{\partial g_8}{\partial u_1^k}\right|_h = -f_8\left(x^h, u^h\right) \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial u_1^k}\right|_h -$$
$$- f_7\left(x^h, u^h\right) \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial u_1^k}\right|_h$$

$$\left.\frac{\partial g_8}{\partial u_2^k}\right|_h = -\left.\frac{\partial f_7}{\partial u_2^k}\right|_h \cdot \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right)$$

$$\left.\frac{\partial g_8}{\partial u_3^k}\right|_h = \left.\frac{\partial f_8}{\partial u_3^k}\right|_h \cdot \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right)$$

$$\left.\frac{\partial g_8}{\partial u_4^k}\right|_h = -f_8\left(x^h, u^h\right) \sin\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial u_4^k}\right|_h -$$
$$- f_7\left(x^h, u^h\right) \cos\left(f_{12}\left(x^h, u^h\right) T \cdot \frac{2\pi}{W_{360}} \right) \cdot T \frac{2\pi}{W_{360}} \cdot \left.\frac{\partial f_{12}}{\partial u_4^k}\right|_h$$

$$\left.\frac{\partial g_{10}}{\partial u_2^k}\right|_h = \frac{E_{4x}}{E_{5x}} \qquad \left.\frac{\partial g_{11}}{\partial u_3^k}\right|_h = \frac{E_{4y}}{E_{5y}}$$

Ecs II.3 Derivadas parciales en el punto de *hover*

A.III Figuras Matlab

Todas las figuras aquí representadas fueron generadas con los programas de Matlab que se crearon para este proyecto y que se explicaron en la sección 4.5. Para todas estas figuras, los valores de Q y de R son los del controlador actual:

$$Q = \begin{bmatrix} 0.1 & & & & & & & & & & & \\ & 0.1 & & & & & & & & & & \\ & & 1 & & & & & & & & & \\ & & & 1 & & & & & & & & \\ & & & & 1 & & & & & & & \\ & & & & & 1 & & & & & & \\ & & & & & & 1 & & & & & \\ & & & & & & & 1 & & & & \\ & & & & & & & & 100 & & & \\ & & & & & & & & & 1000 & & \\ & & & & & & & & & & 1 & \end{bmatrix}$$

$$R = \begin{bmatrix} 10000 & & & & & \\ & 1000 & & & & \\ & & 1000 & & & \\ & & & 50000 & & \\ & & & & 1000 & \end{bmatrix}$$

Que son sencillas matrices diagonales (y por tanto simétricas) que penalizan mucho más la actuación que el estado. Por, ejemplo penalizan mucho más la actuación en el colectivo o en el rotor de cola que la posición fuera del equilibrio en el plano horizontal. Esta predominancia de R frente a Q resulta en una respuesta lenta pero suave. Un ajuste más fino quedaba fuera de las competencias del presente proyecto.

En las Fig II.2 se puede ver la evolución de la simulación de un vuelo concreto con este controlador, en el que el helicóptero describe una especie de “ocho” de 8x8 metros con despegue, bajadas, subidas y aterrizaje incluidos.

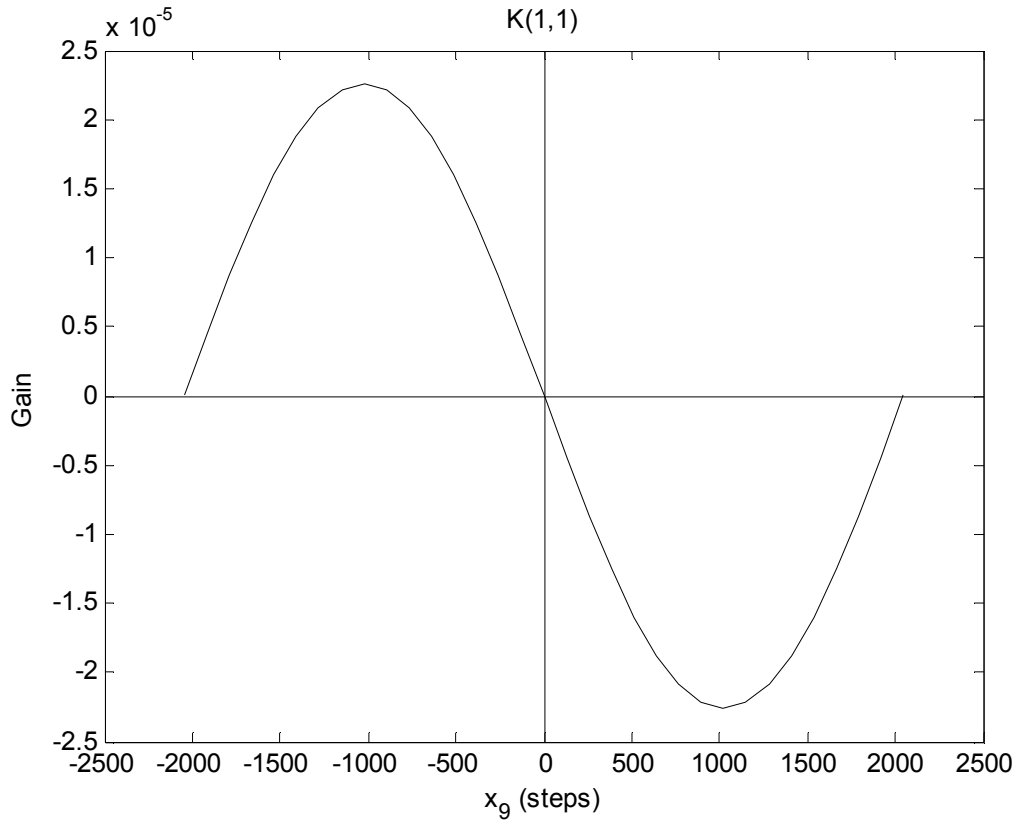

Fig III.1.1 gnrKij (i = 1, j = 1)

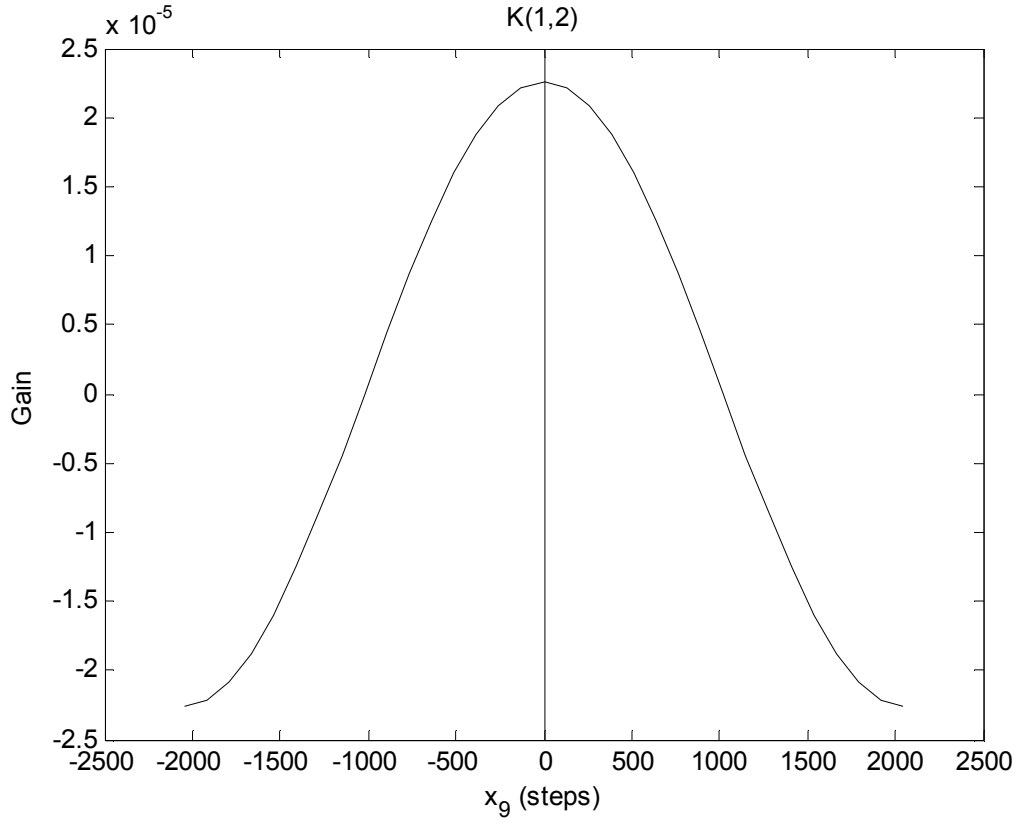

Fig III.1.2 gnrKij (i = 1, j = 2)

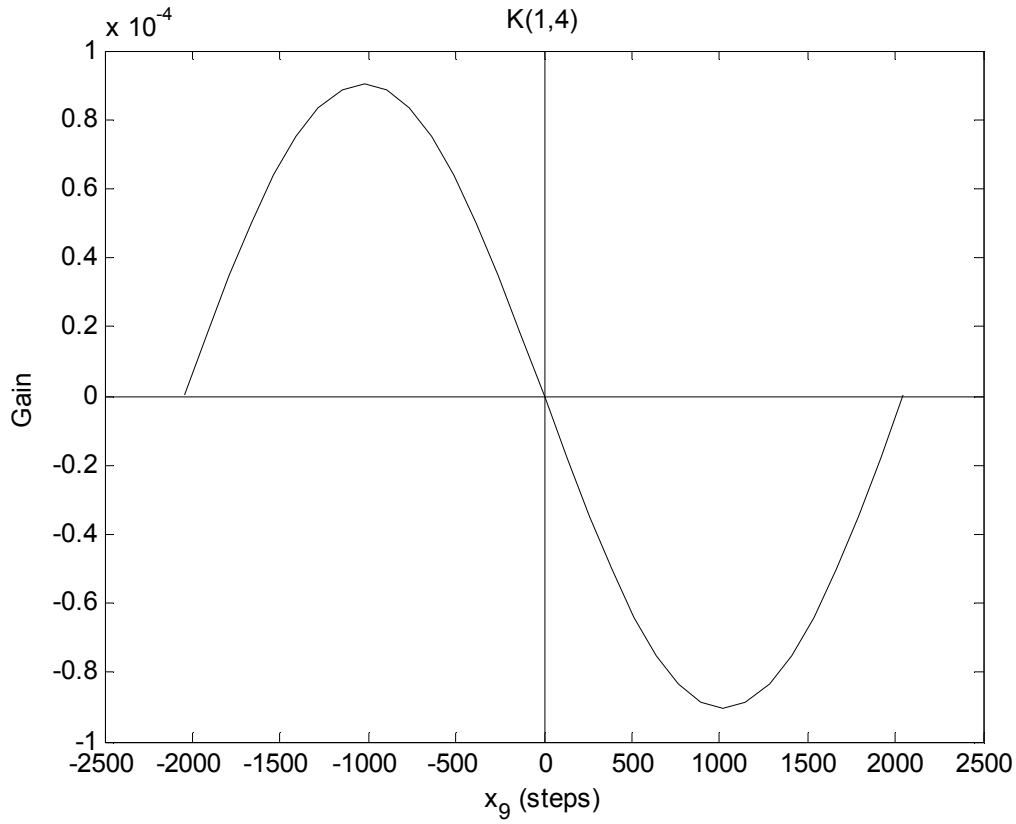

Fig III.1.3 gnrKij (i = 1, j = 4)

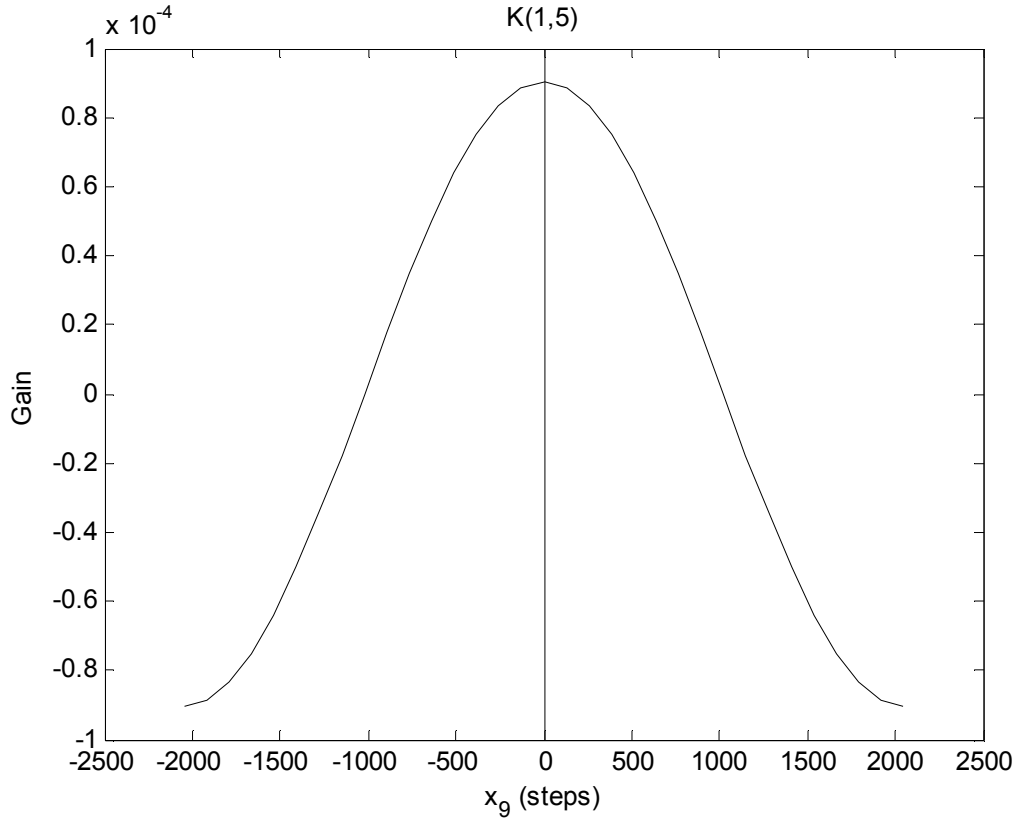

Fig III.1.4 gnrKij (i = 1, j = 5)

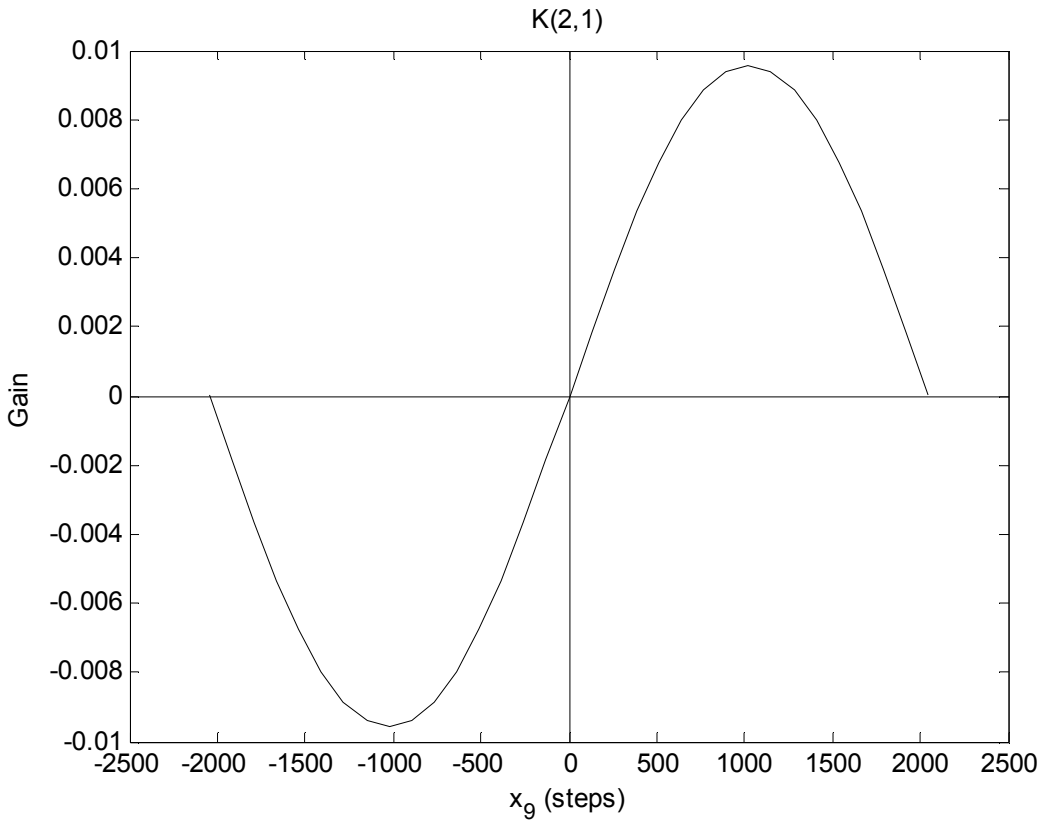

Fig III.1.5 gnrKij (i = 2, j = 1)

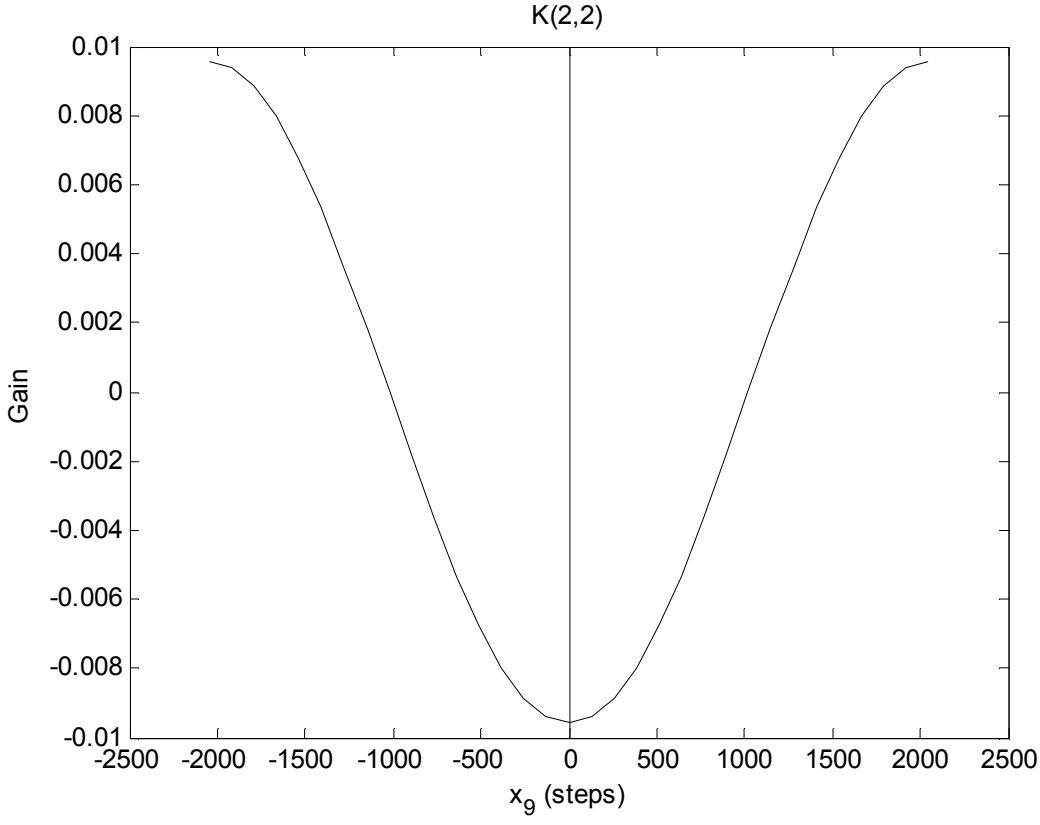

Fig III.1.6 gnrKij (i = 2, j = 2)

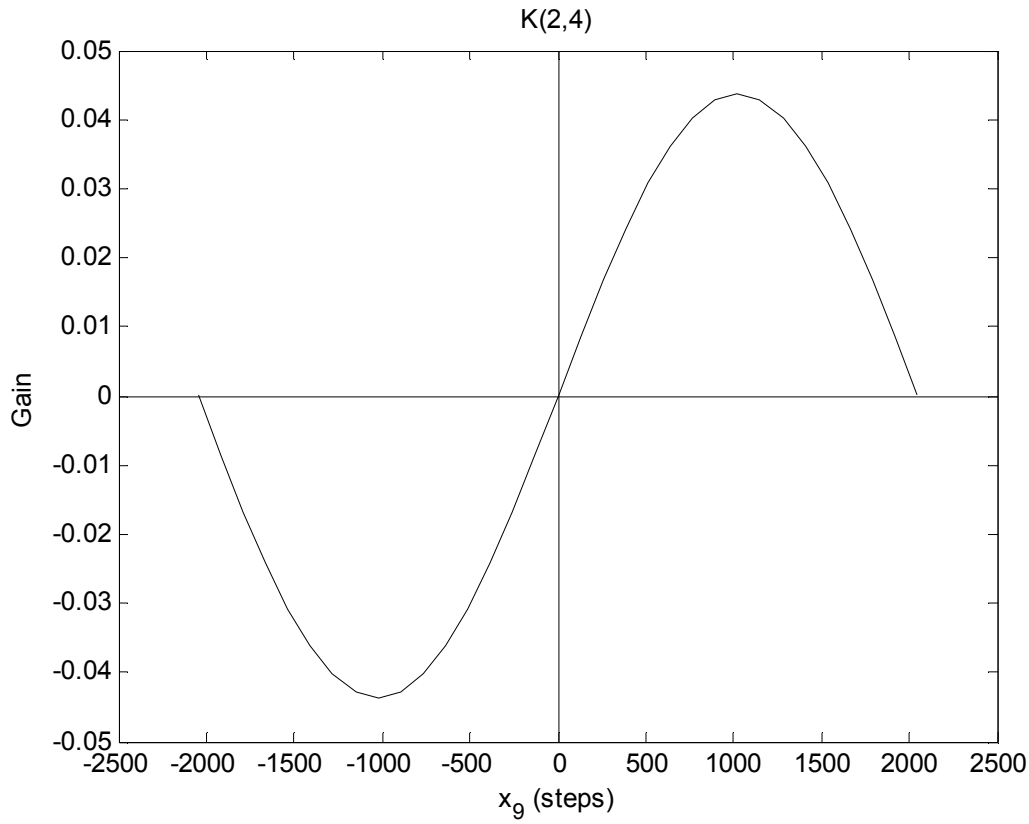

Fig III.1.7 gnrKij (i = 2, j = 4)

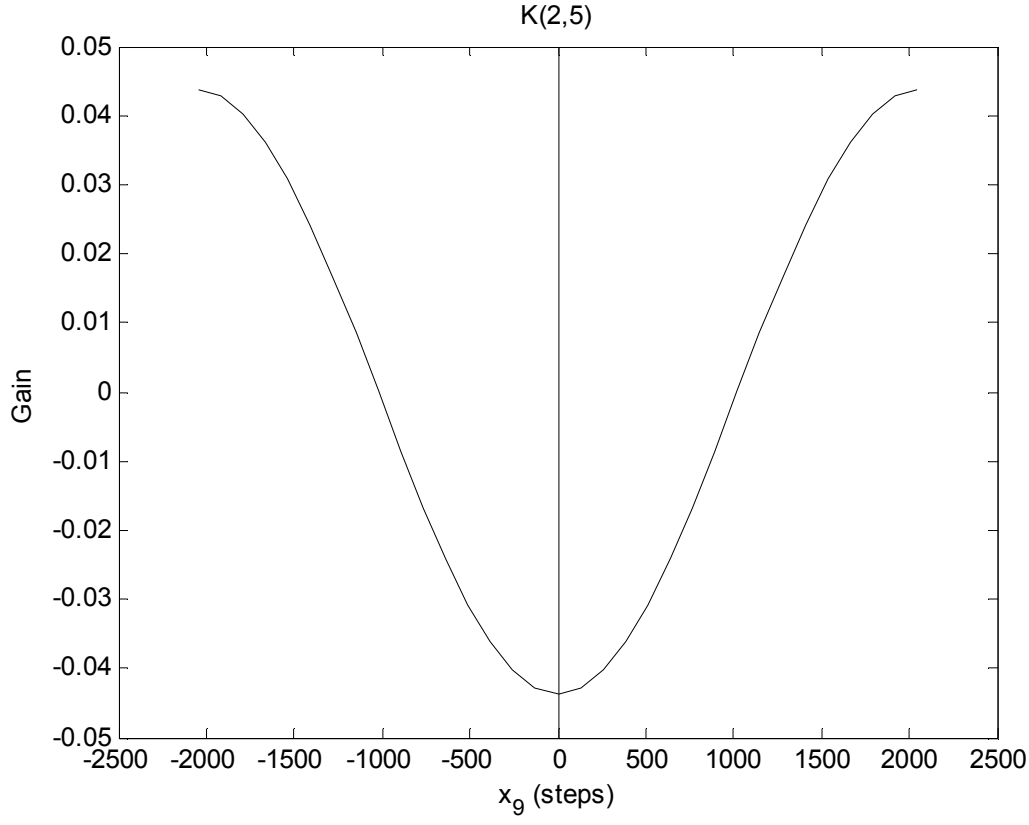

Fig III.1.8 gnrKij (i = 2, j = 5)

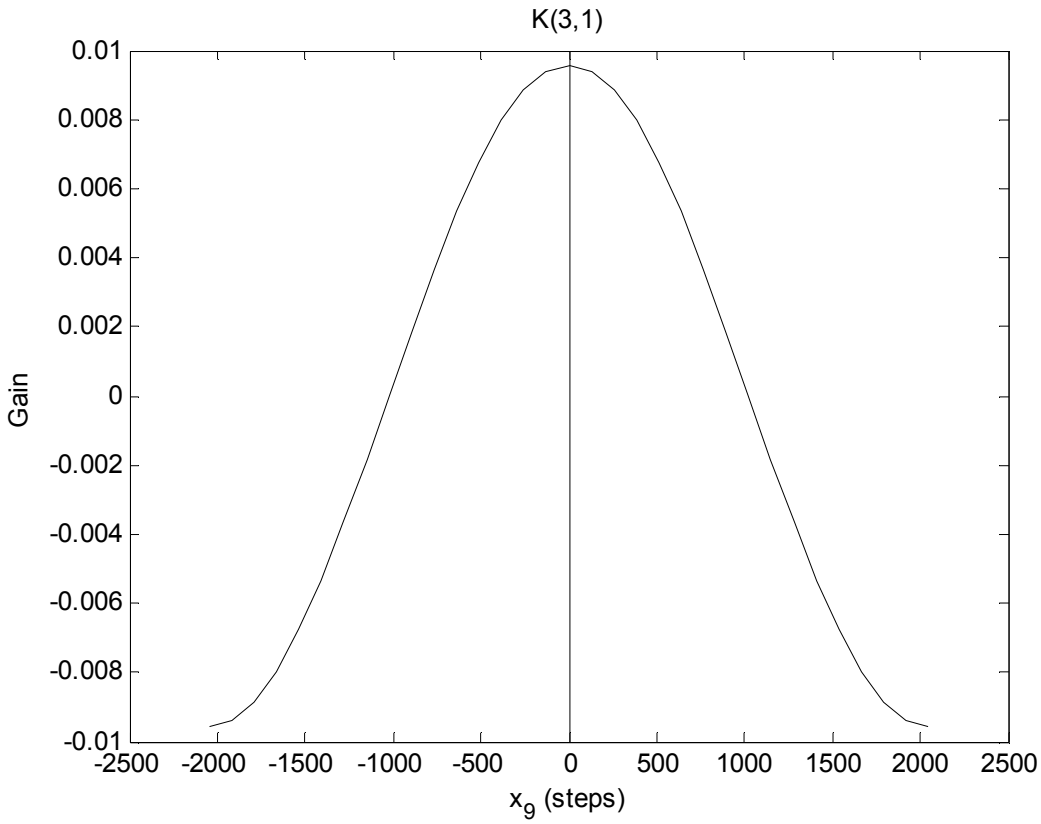

Fig III.1.9 gnrKij (i = 3, j = 1)

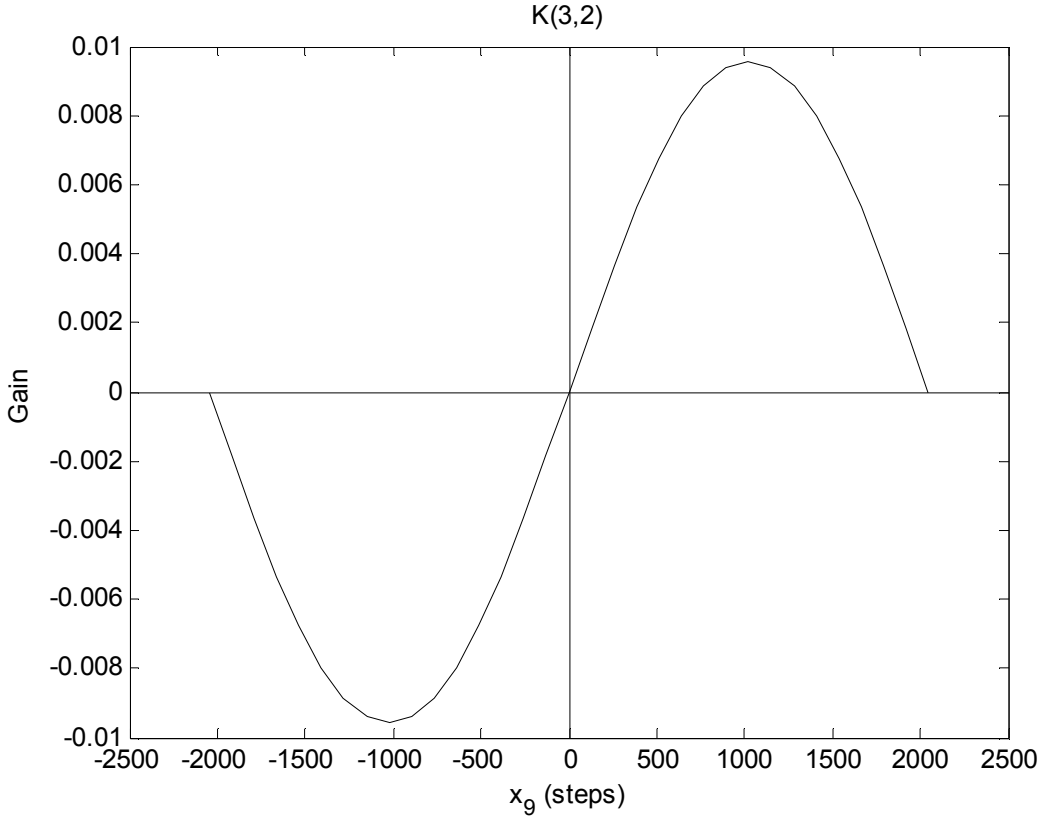

Fig III.1.10 gnrKij (i = 3, j = 2)

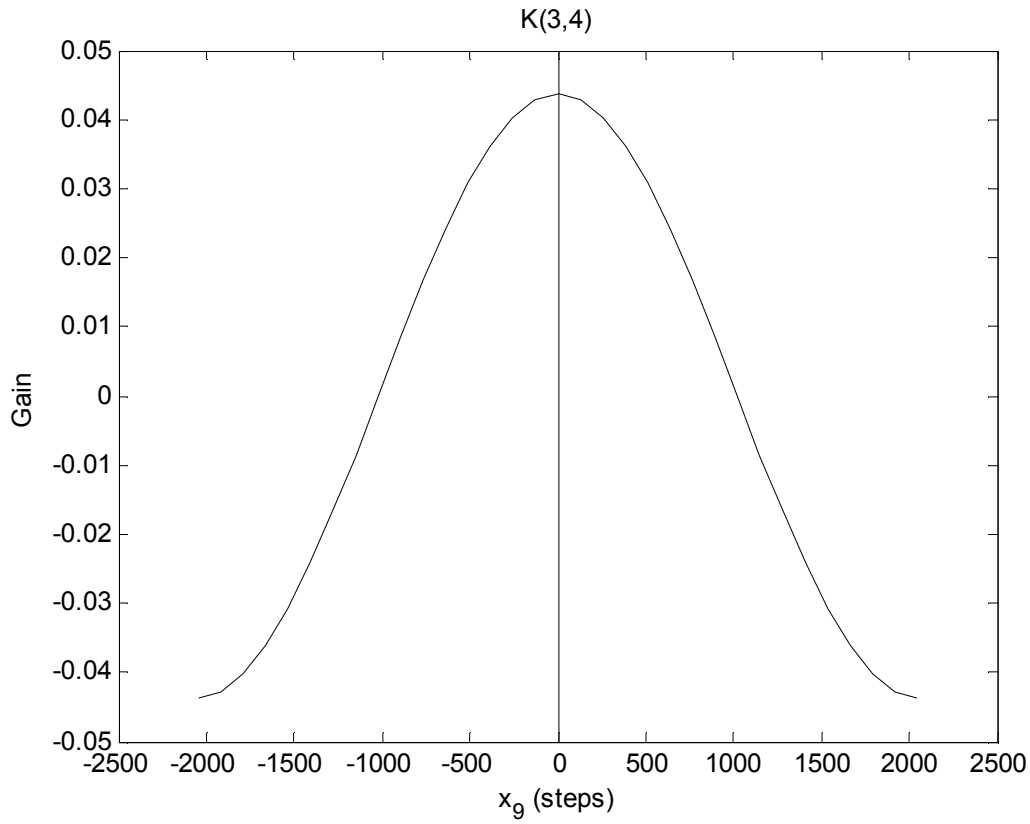

Fig III.1.11 gnrKij (i = 3, j = 4)

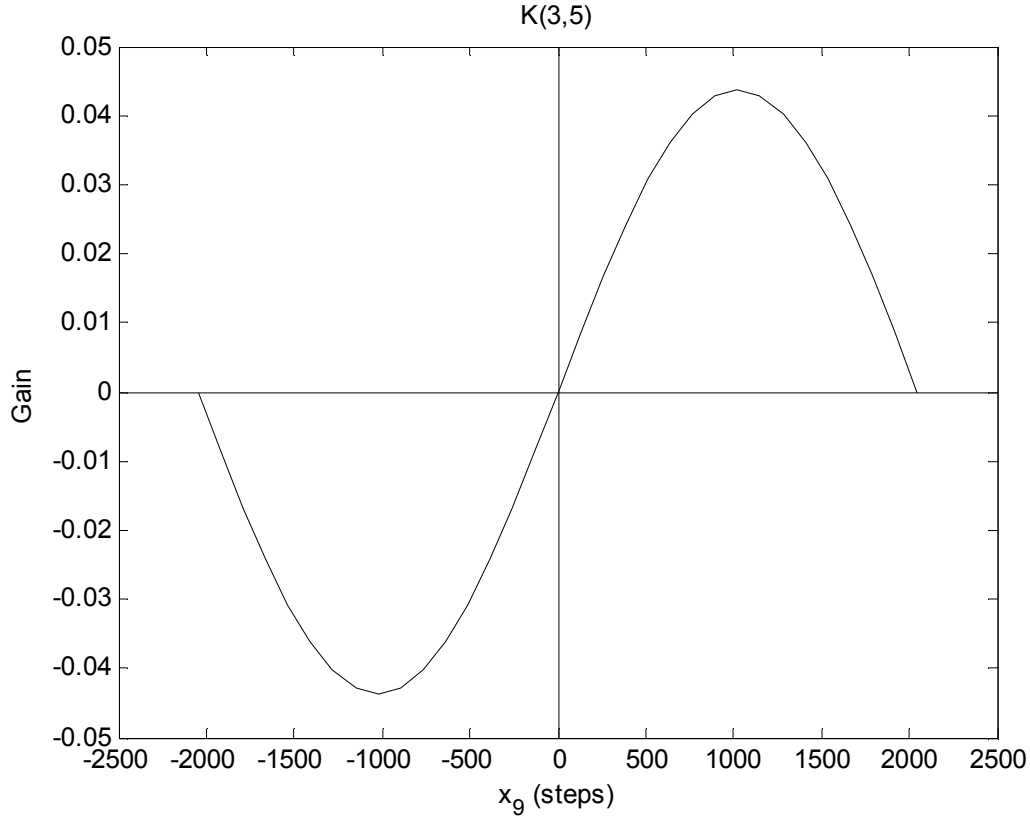

Fig III.1.12 gnrKij (i = 3, j = 5)

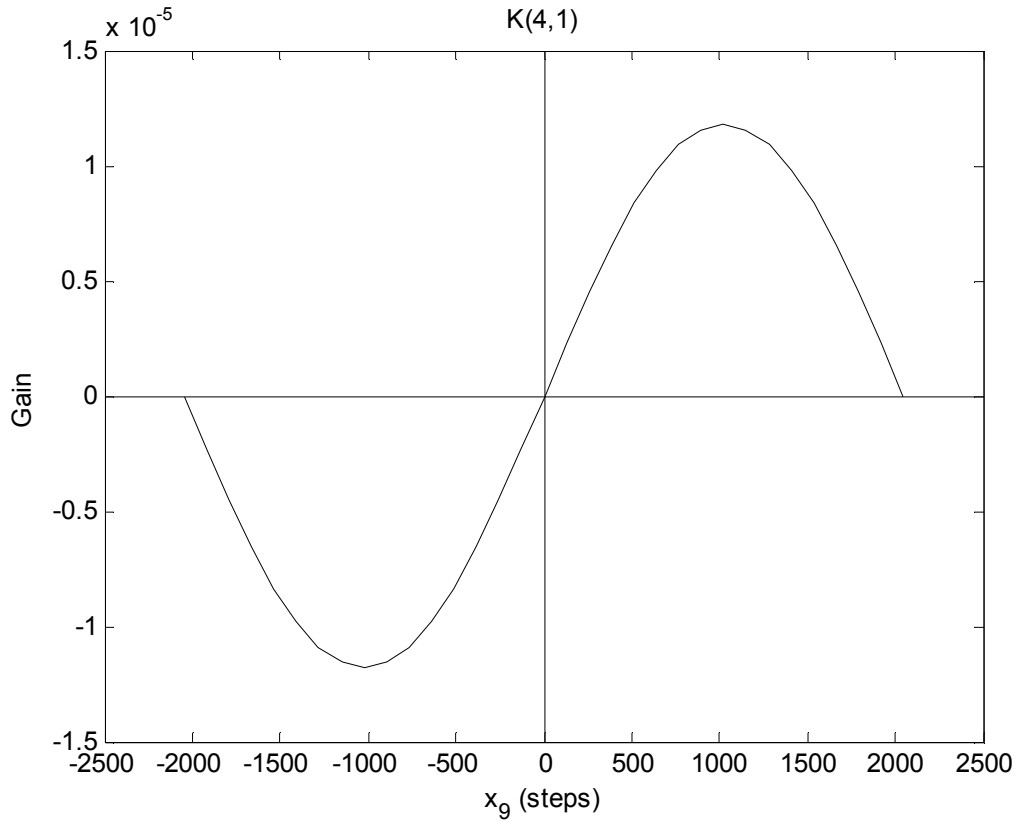

Fig III.1.13 gnrKij (i = 4, j = 1)

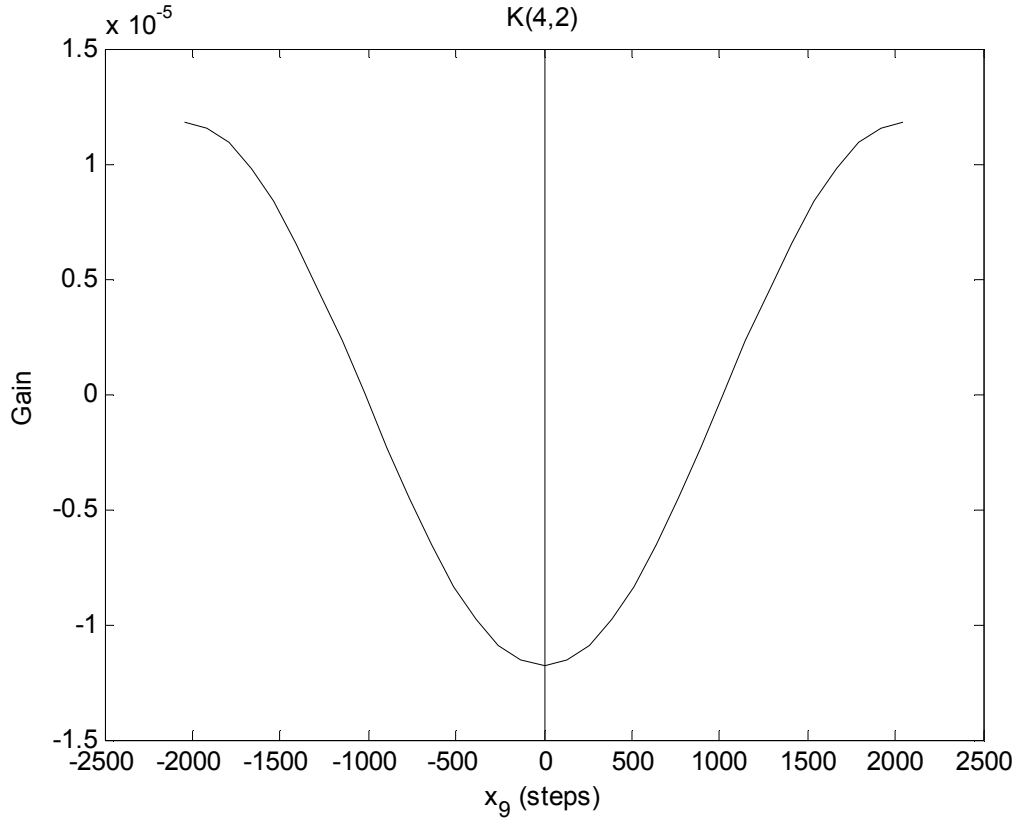

Fig III.1.14 gnrKij (i = 4, j = 2)

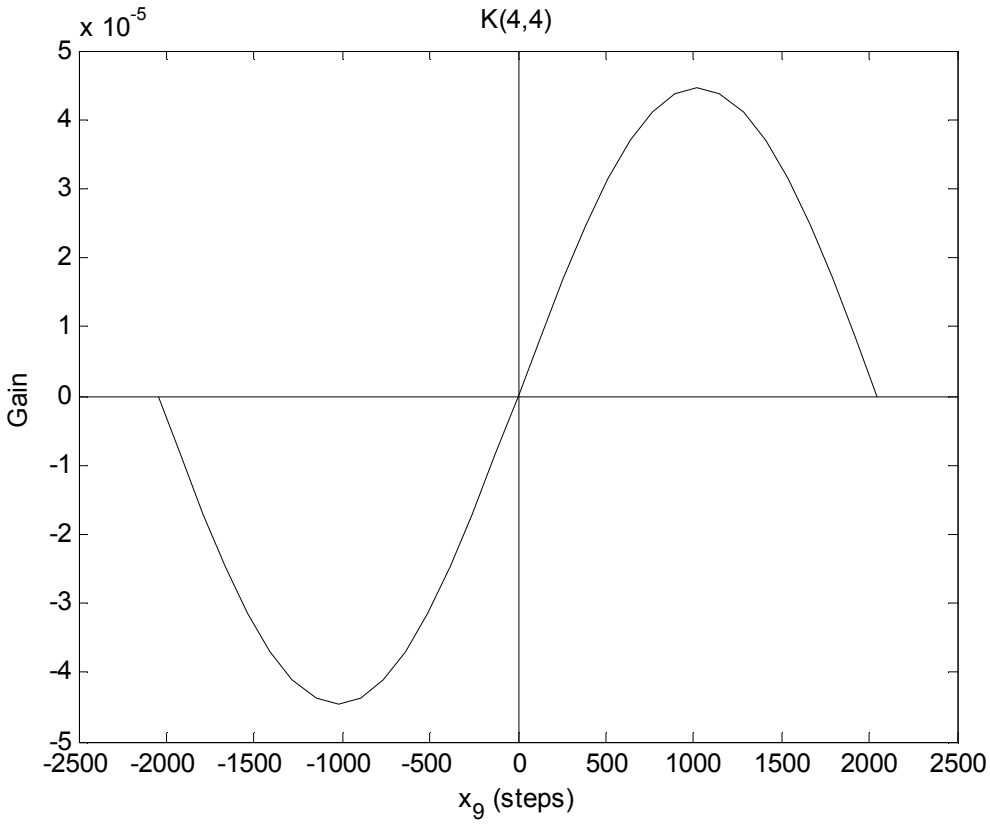

Fig III.1.15 gnrKij (i = 4, j = 4)

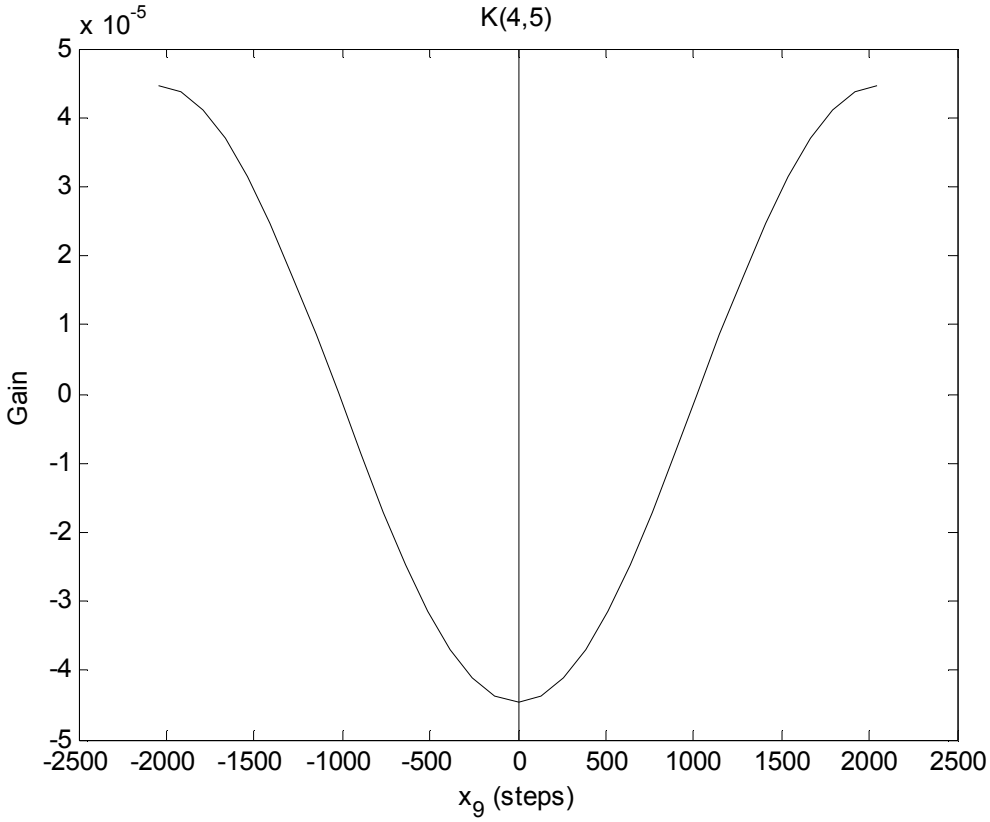

Fig III.1.16 gnrKij (i = 4, j = 5)

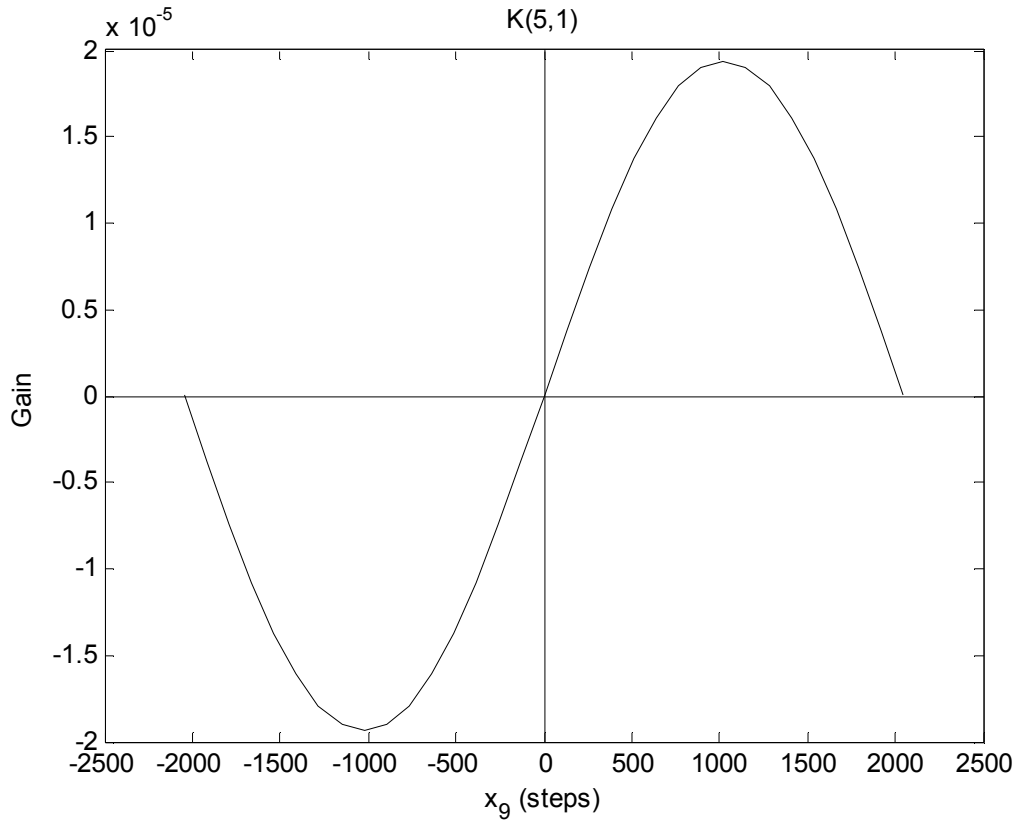

Fig III.1.17 gnrKij (i = 5, j = 1)

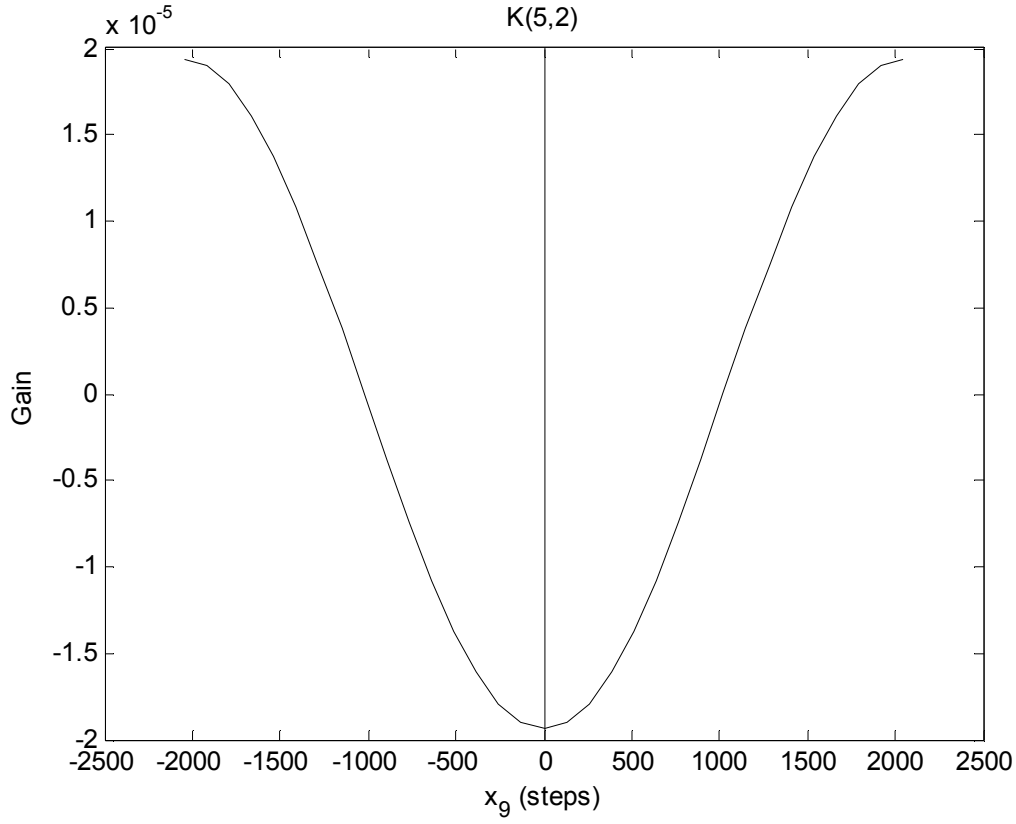

Fig III.1.18 gnrKij (i = 5, j = 2)

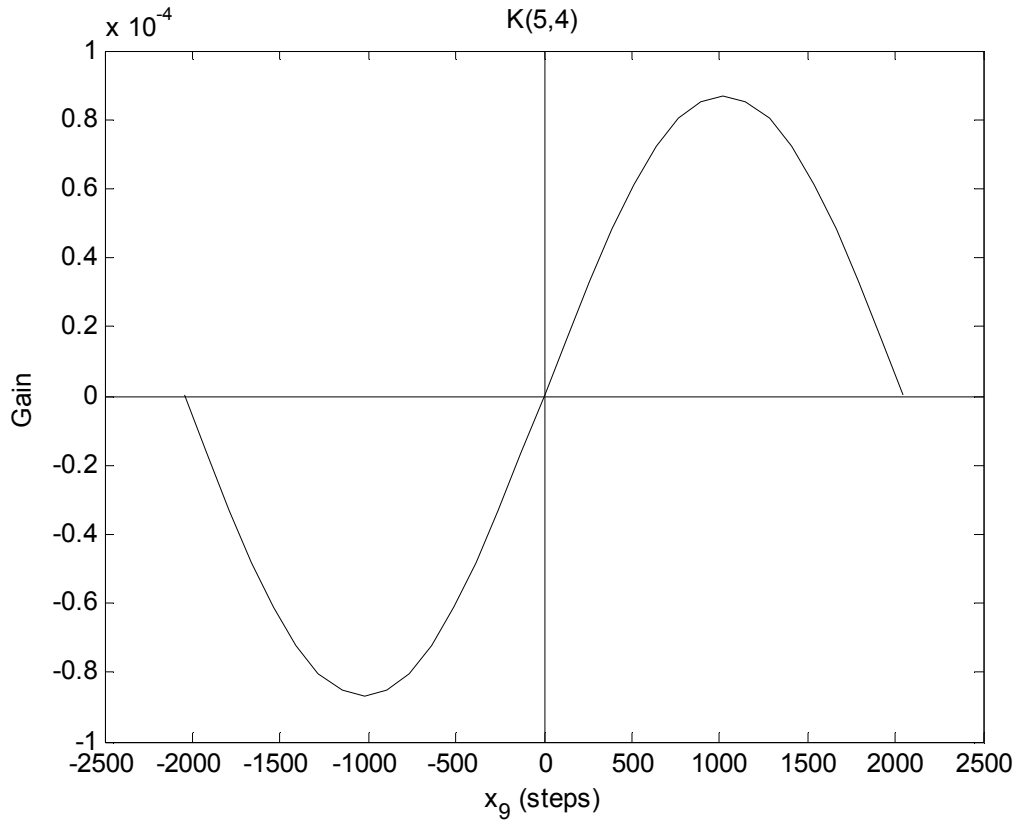

Fig III.1.19 gnrKij (i = 5, j = 4)

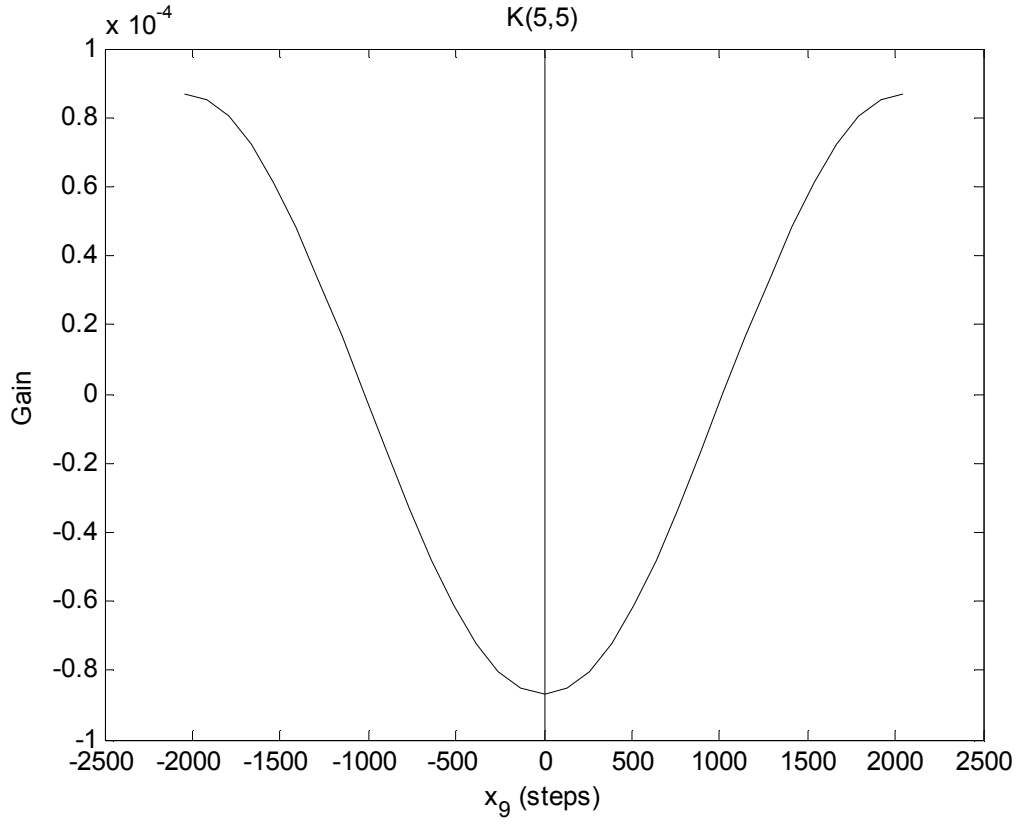

Fig III.1.20 gnrKij (i = 5, j = 5)

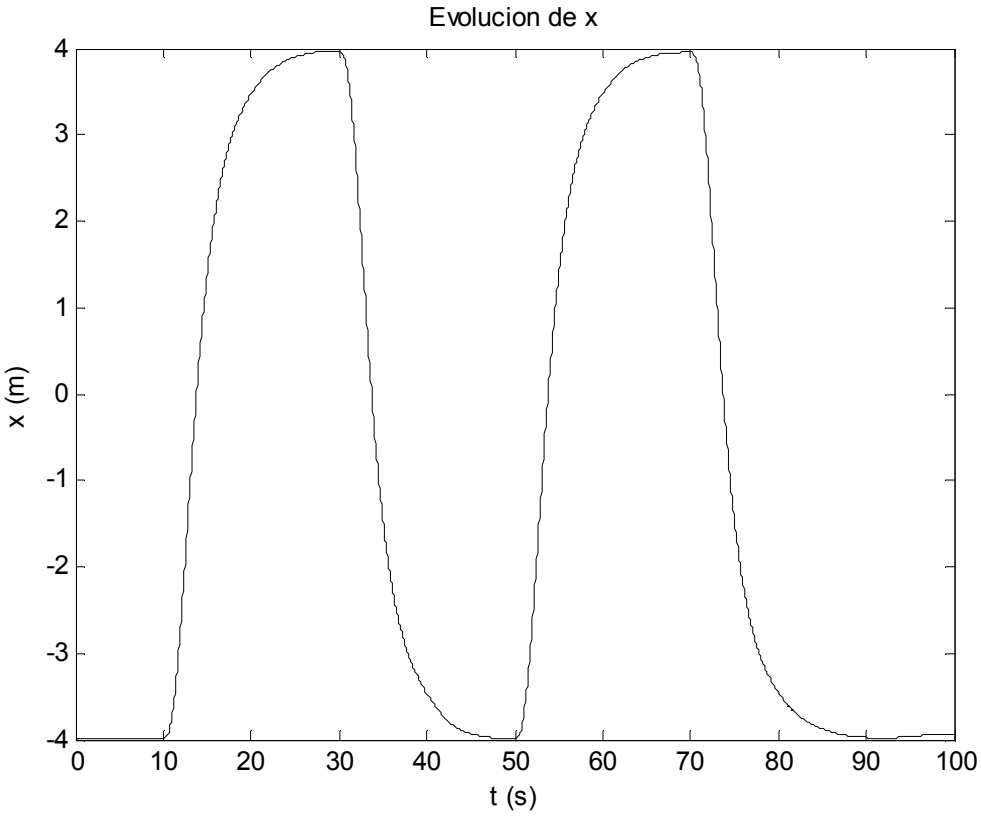

Fig III.2.1

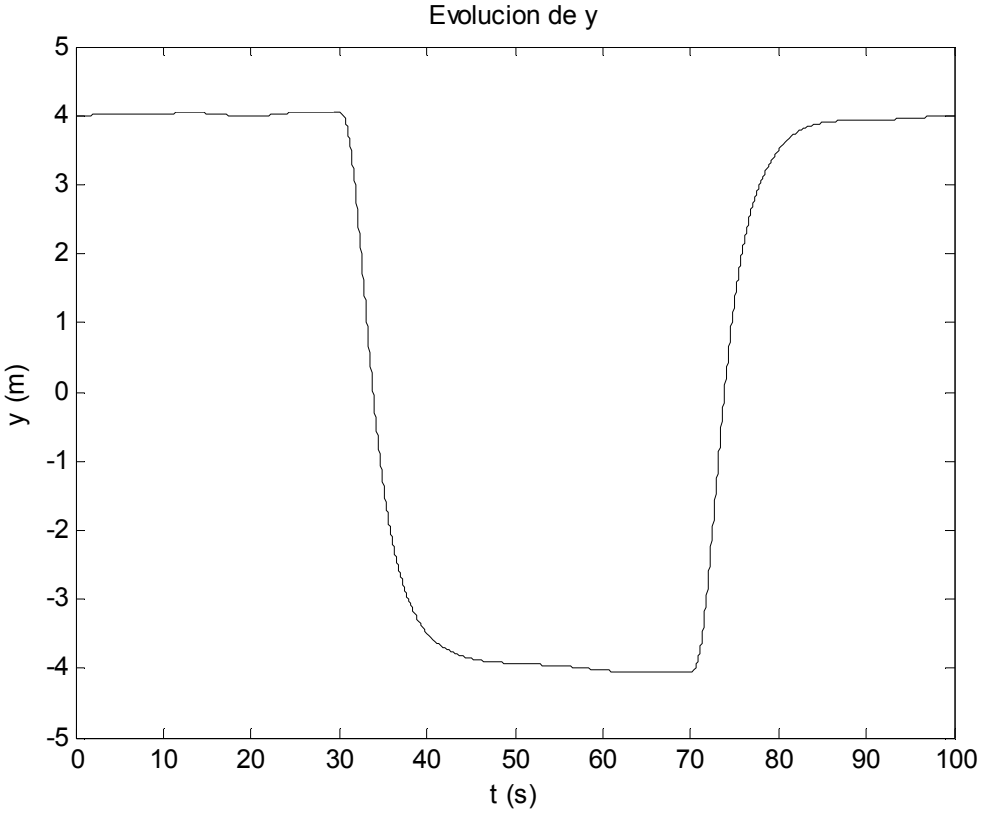

Fig III.2.2

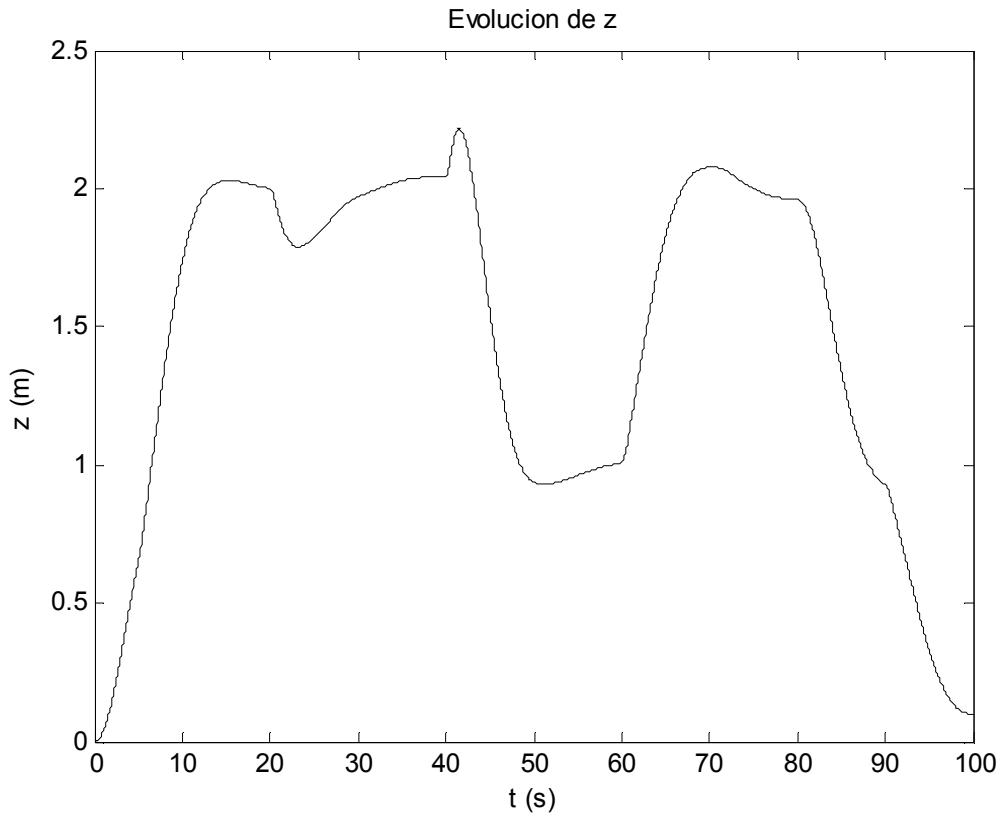

Fig III.2.3

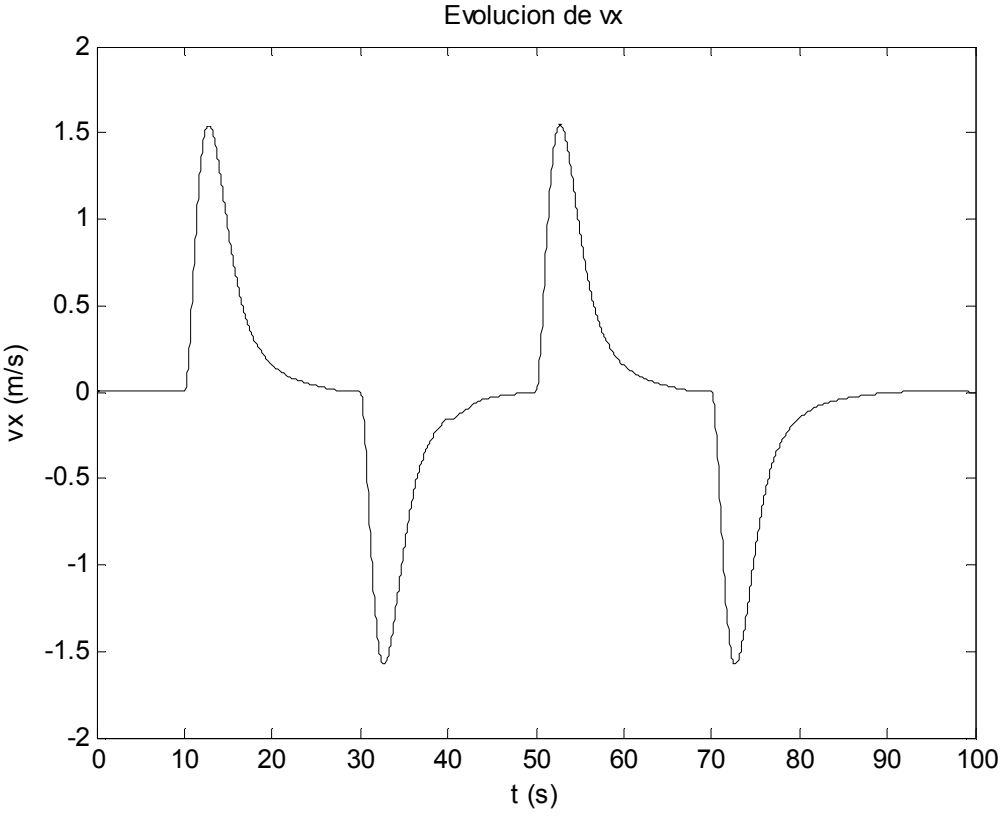

Fig III.2.4

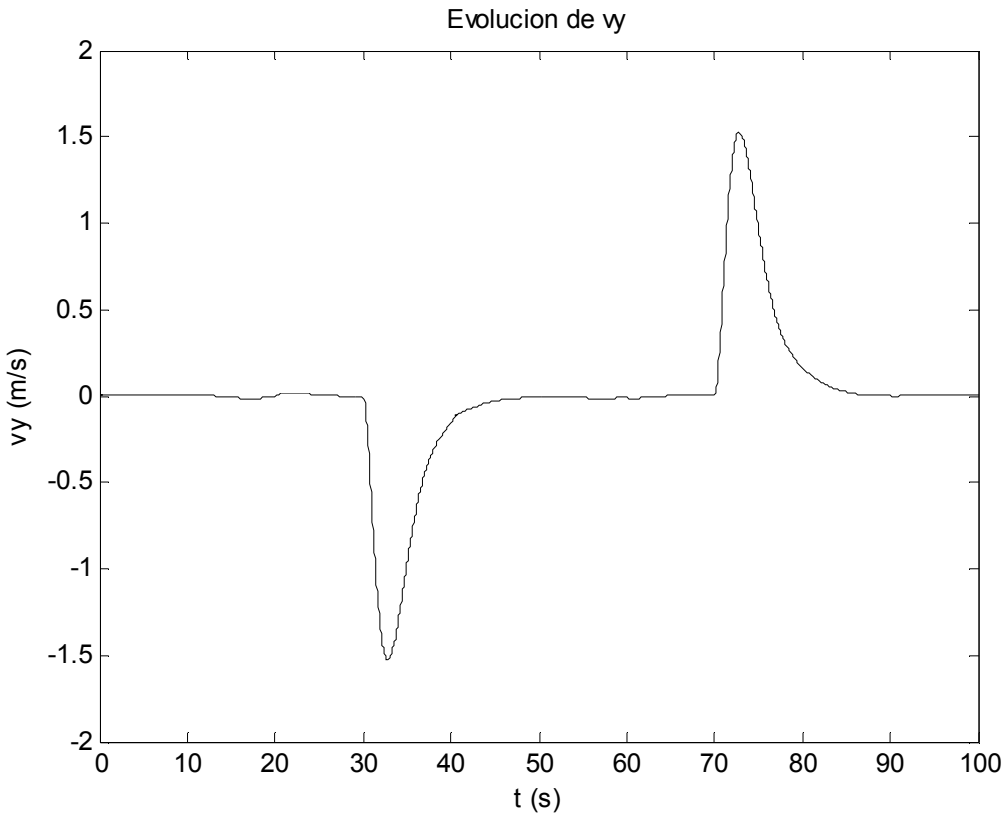

Fig III.2.5

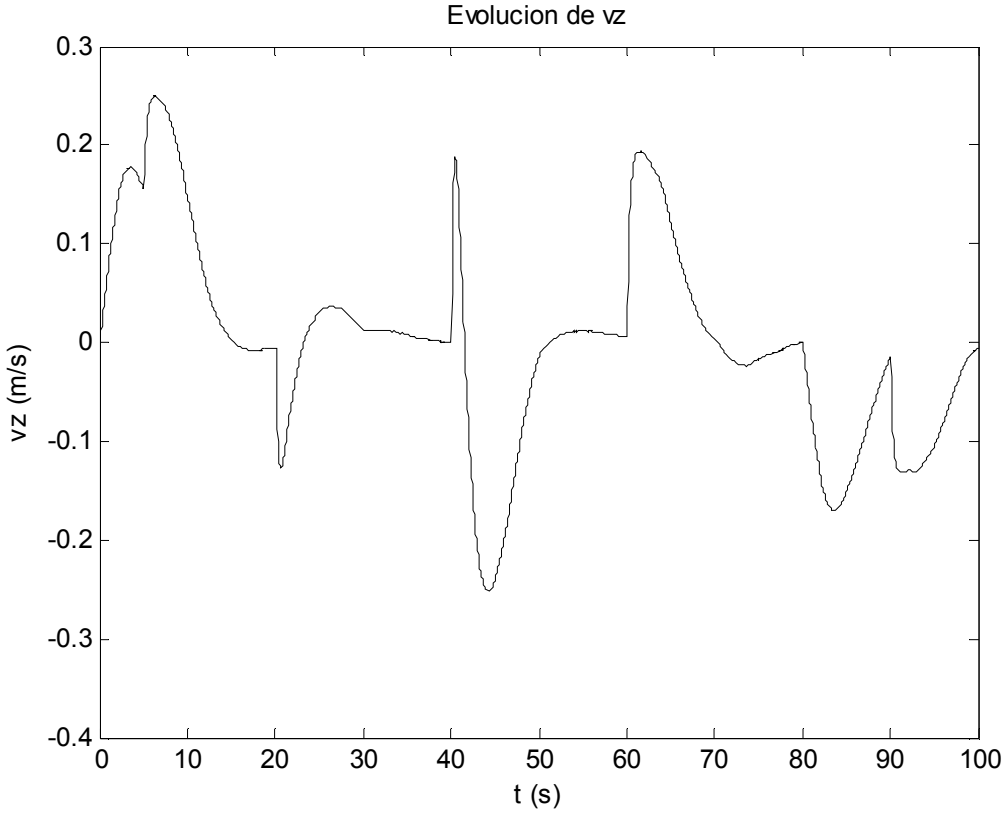

Fig III.2.6

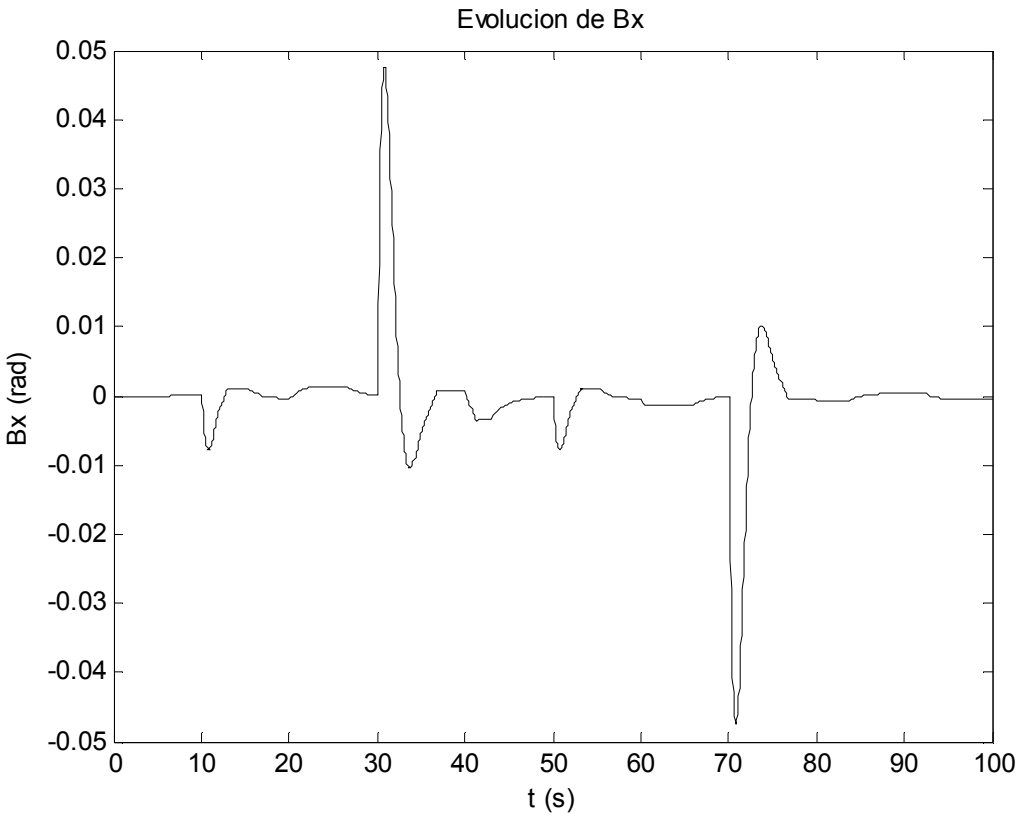

Fig III.2.7

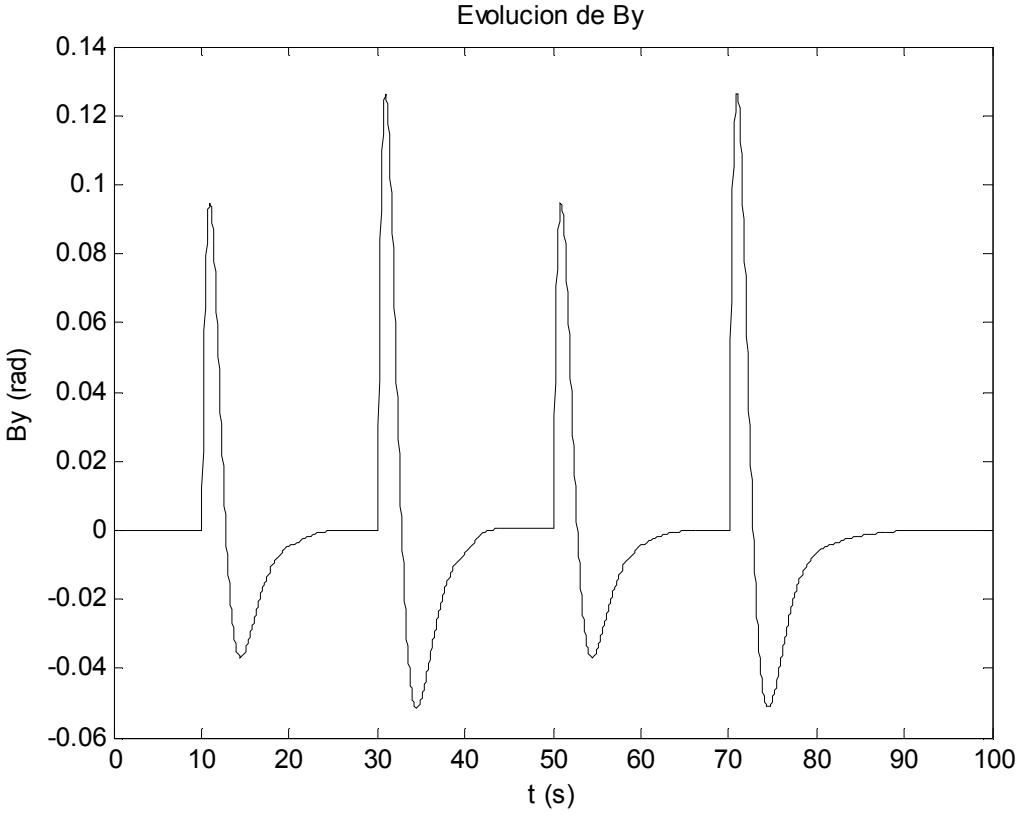

Fig III.2.8

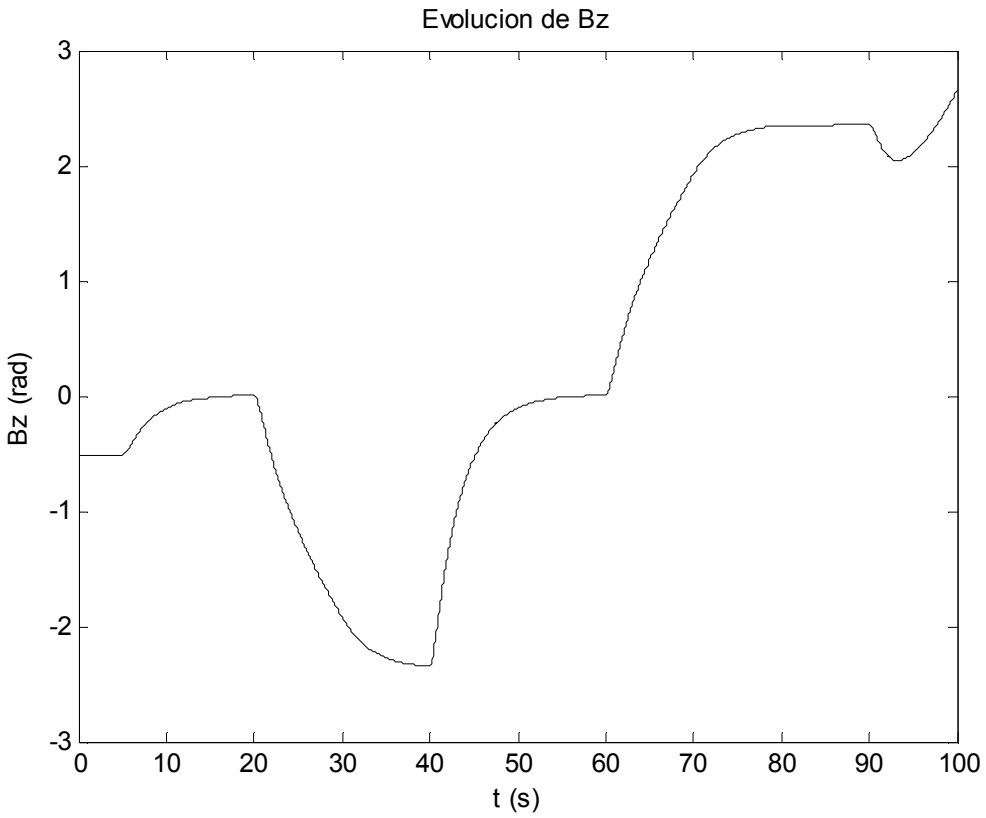

Fig III.2.9

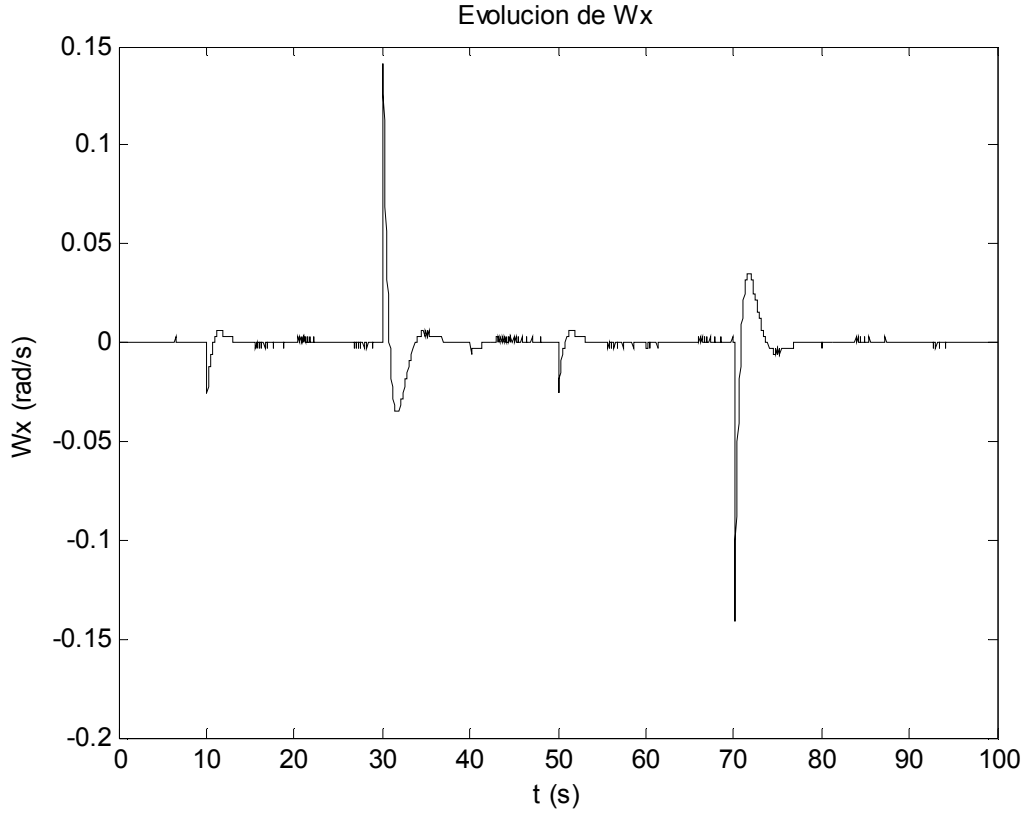

Fig III.2.10

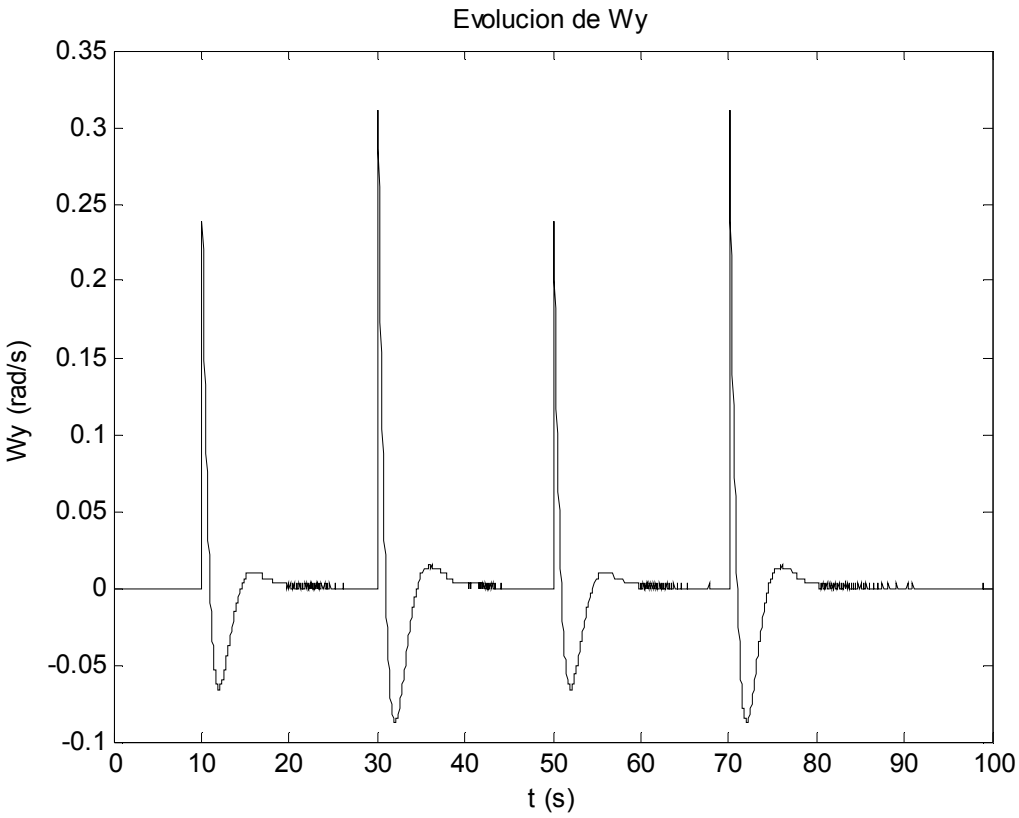

Fig III.2.11

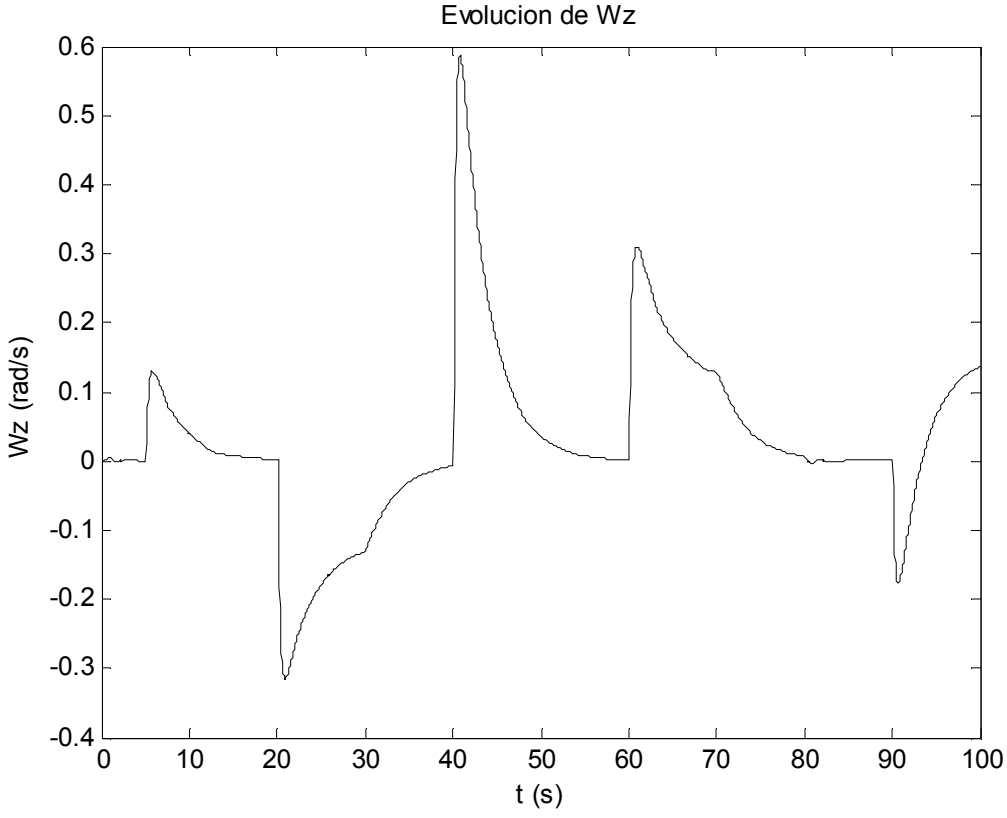

Fig III.2.12

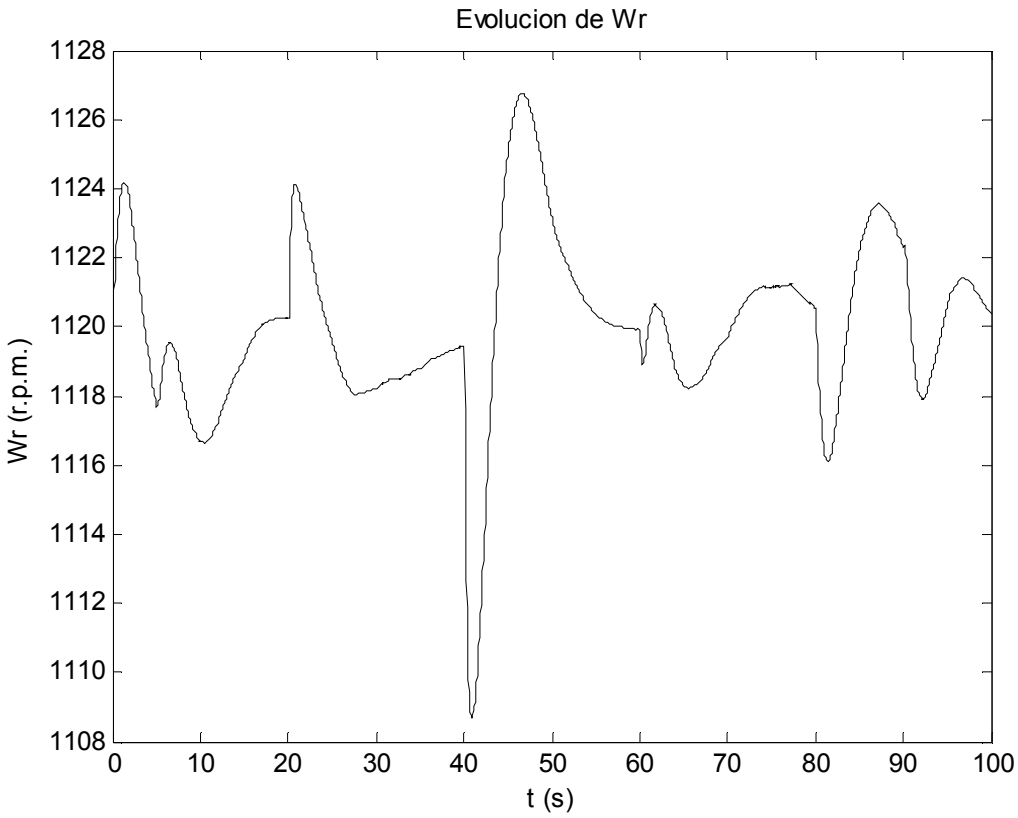

Fig III.2.13

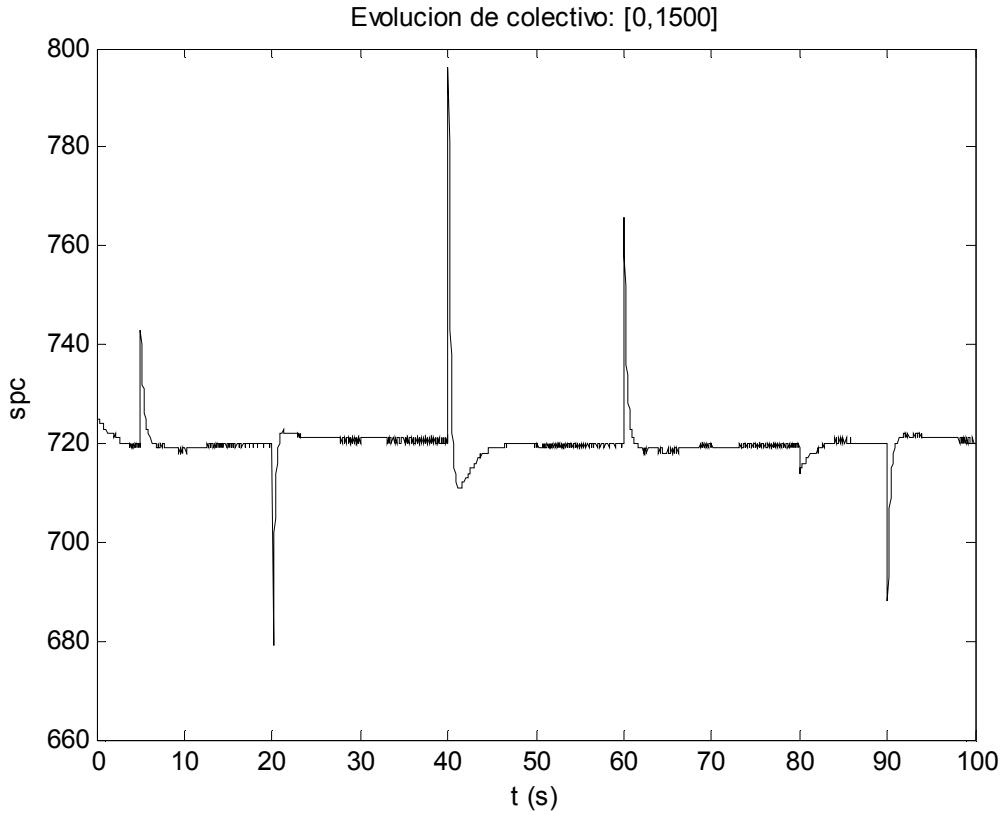

Fig III.2.14

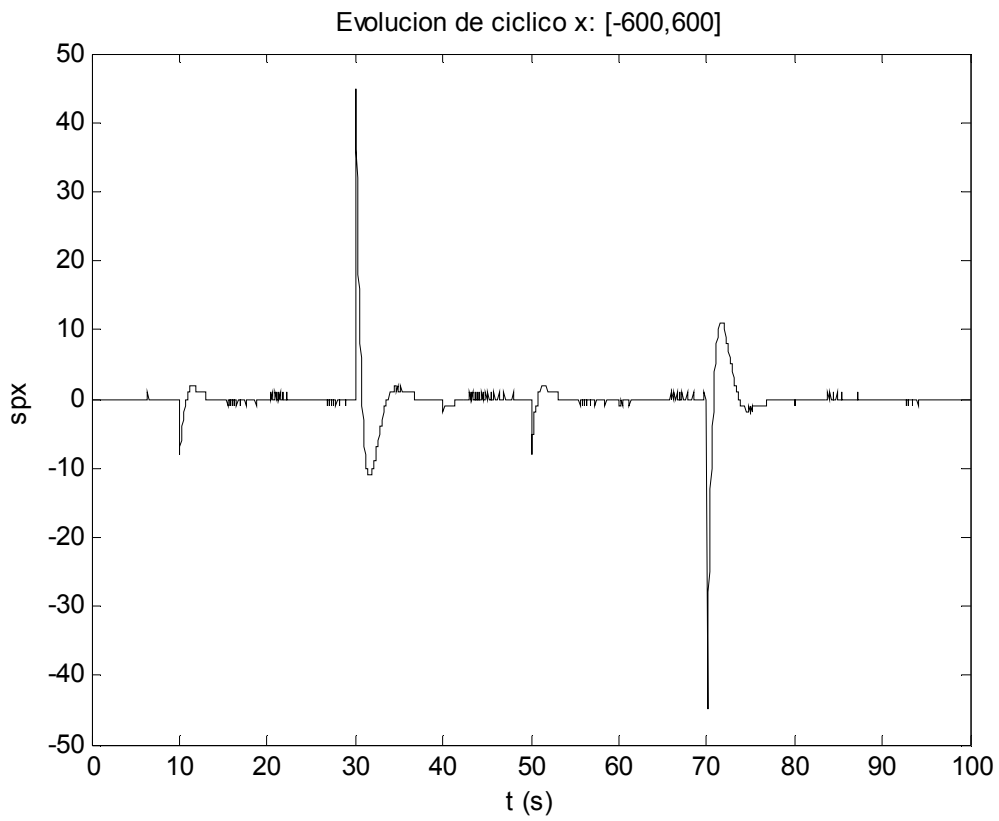

Fig III.2.15

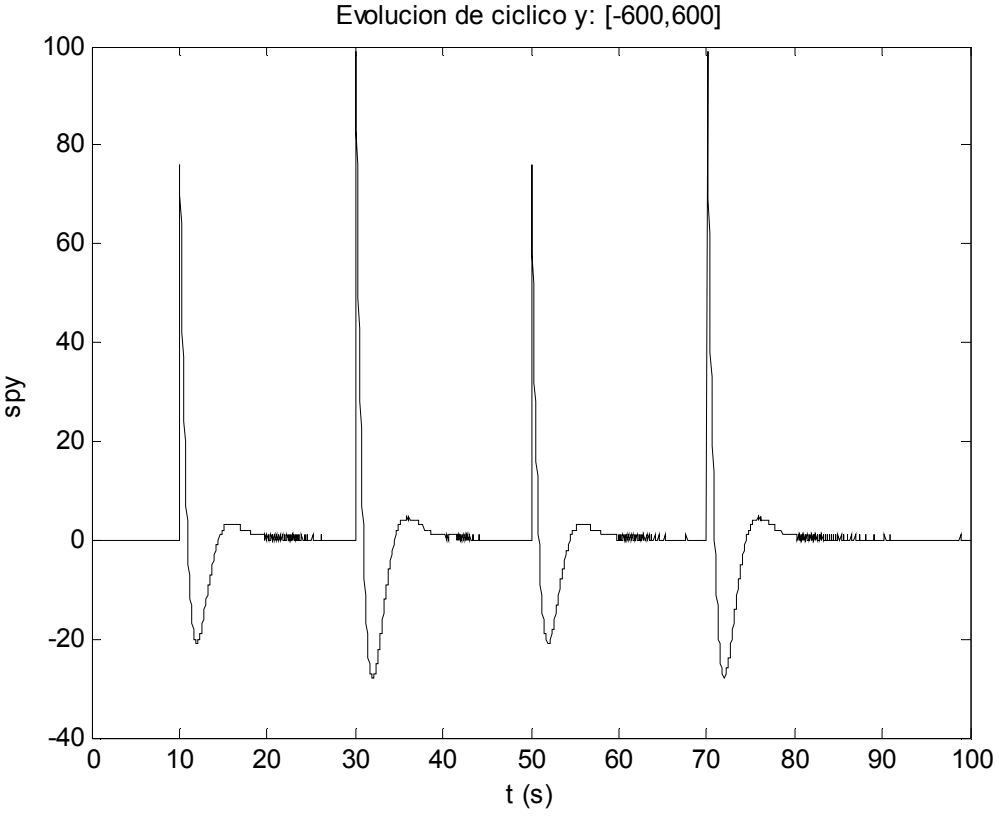

Fig III.2.16

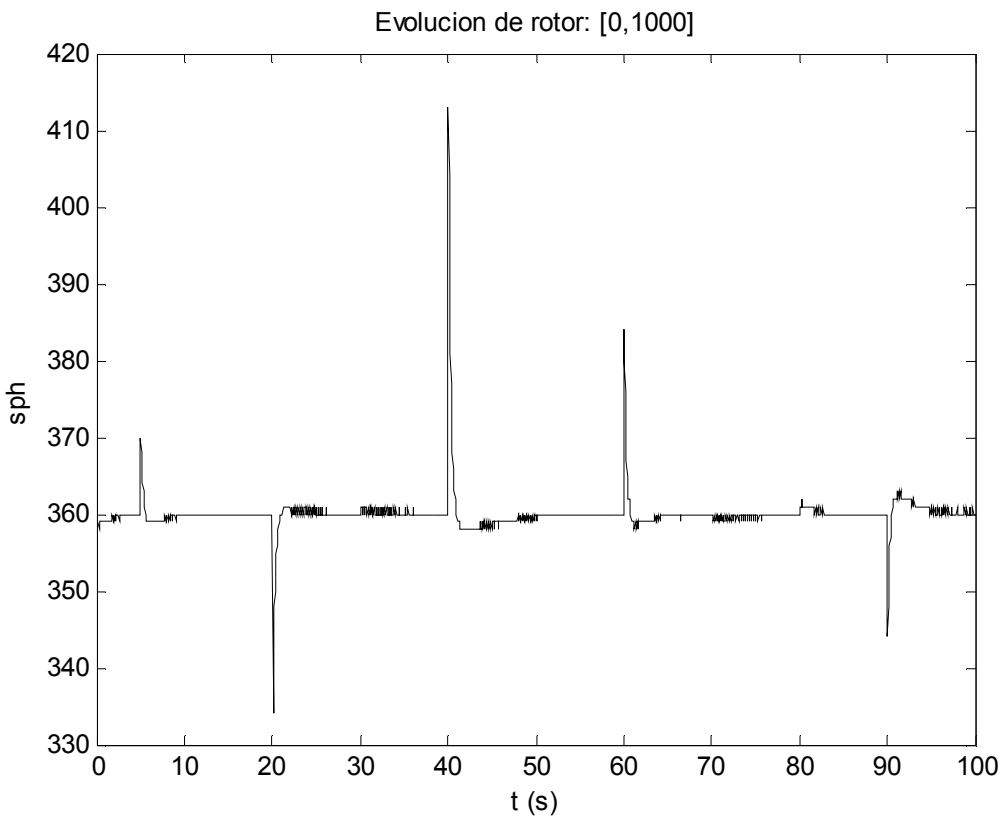

Fig III.2.17

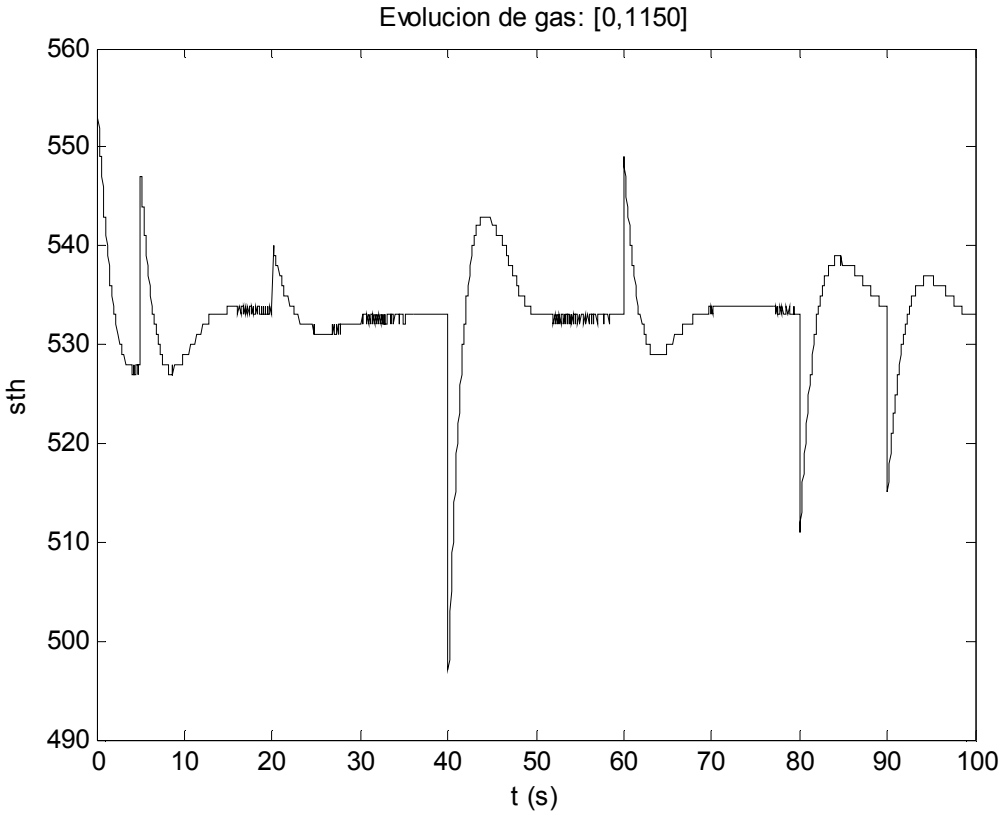

Fig III.2.18

Trayectoria generada

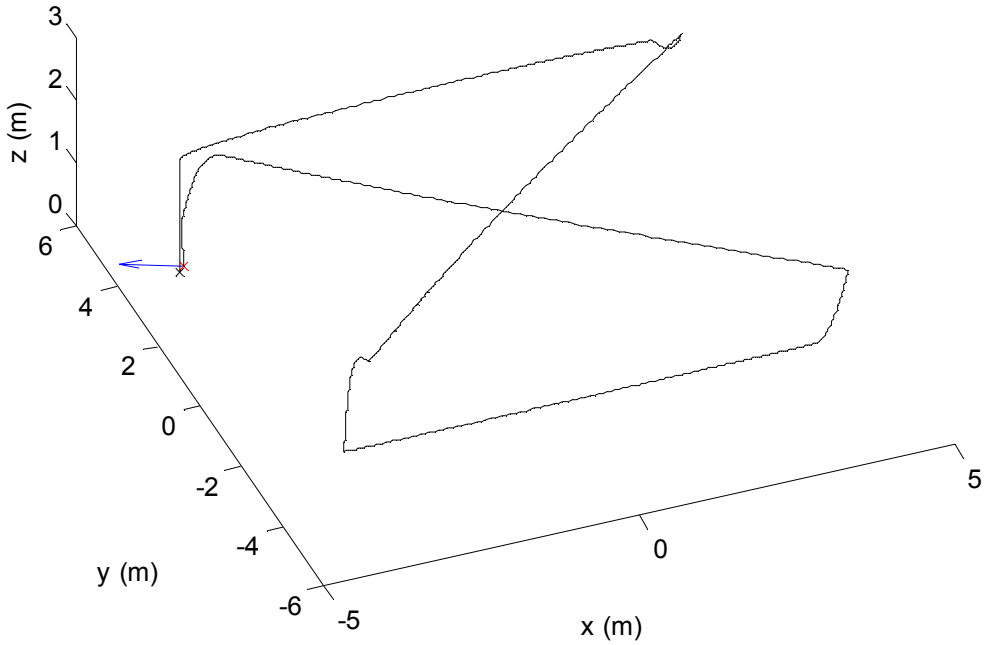

Fig III.2.19

A.IV Figuras de apoyo

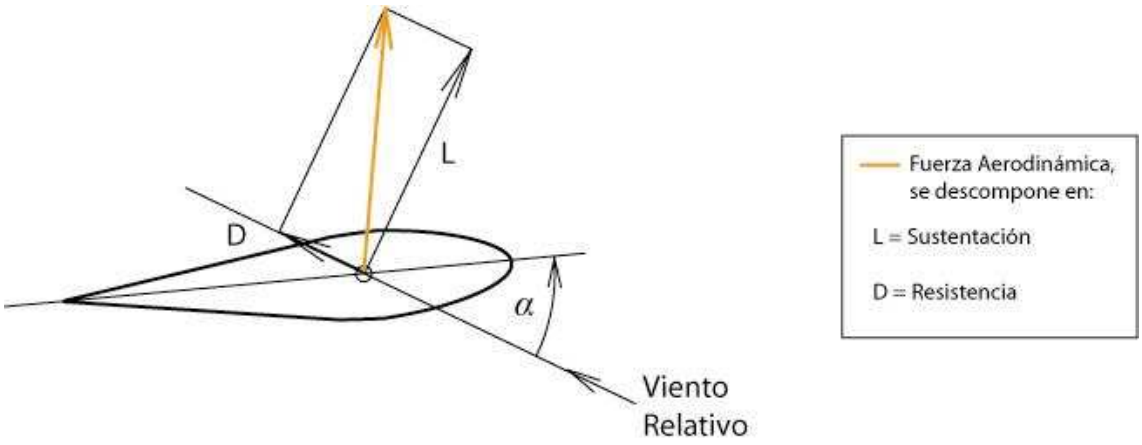

Fig IV.1 Fuerzas aerodinámicas sobre el perfil de la pala

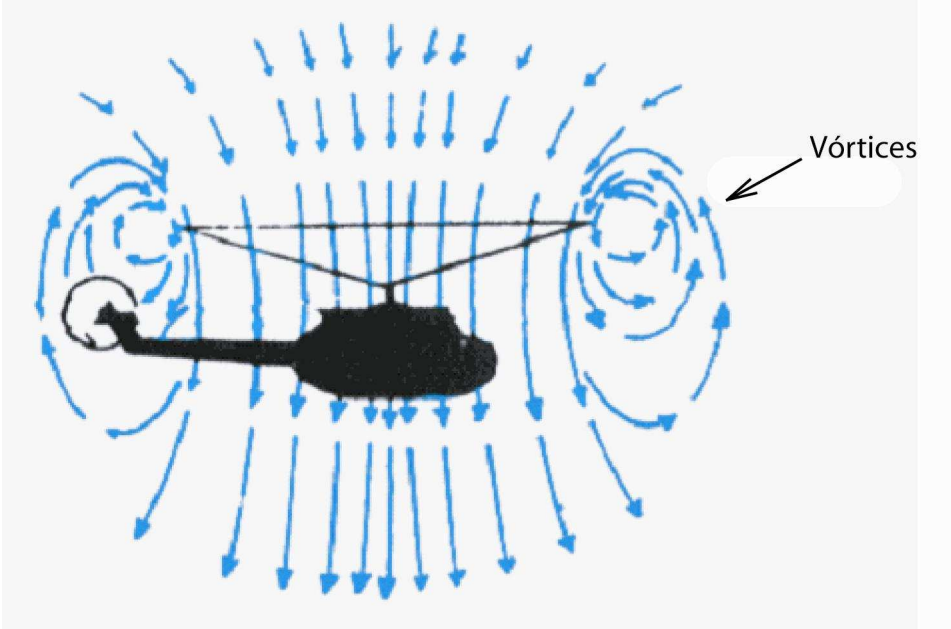

Fig IV.2.1 Estacionario fuera del efecto suelo

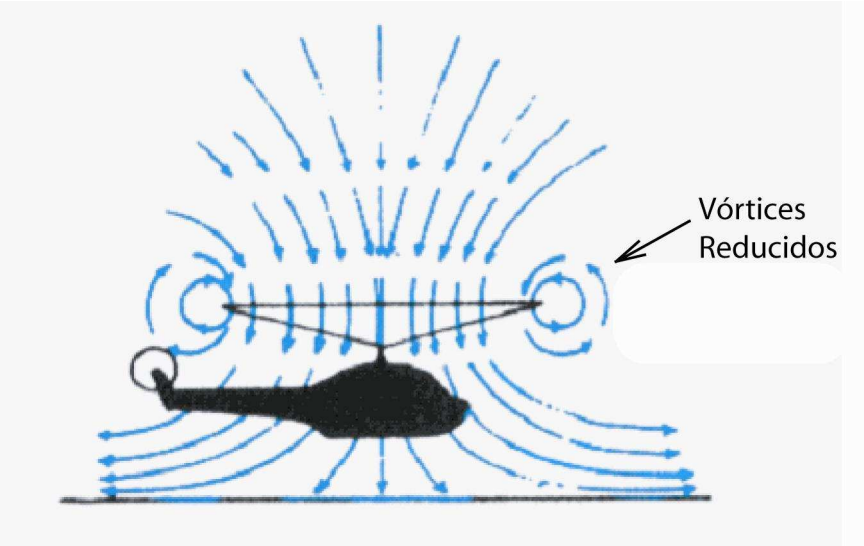

Fig IV.2.2 Reducción de vórtices en el estacionario por el efecto suelo

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