FLYING AN F16

A knowledge base describing the situations an F16 pilot might encounter

Mouthaan, Quint

Technical Report DKS-02-03 / ACE 01
Version 1.0, September, 2002

Mediamatics / Data and Knowledge Systems group
Department of Information Technology and Systems
Delft University of Technology, The Netherlands

Mouthaan, Quint M. (q.m.mouthaan@its.tudelft.nl)

"Flying an F16: A knowledge base describing the situations an F16 pilot might encounter"

Technical Report DKS-02-99 / ACE 01
Version 1.0, September, 2002

Mediamatics / Data and Knowledge Systems group
Department of Information Technology and Systems
Delft University of Technology, The Netherlands

http://www.kbs.twi.tudelft.nl/Research/Projects/ACE/

Keywords: ACE project, artificial intelligence, knowledge base, F16.

Contents

Chapter 1

Introduction

1.1 Project description

This document has been written in the course of the ACE (Adaptive Cockpit Environment) project, which is a cooperation of Delft University of Technology, the National Aerospace Laboratory NLR in the Netherlands and the Czech military academy in Brno. The goal of the ACE project is to research the usefulness and effectiveness of a system that adapts the cockpit environment of an F16 fighter jet depending on the situation the fighter is in and the condition of the pilot. This document describes a knowledge base that contains knowledge about the situations that can occur during a mission and the actions the pilot should take in those situations. This knowledge base can be a basis for programs that determine the current situation and make a judgment about the actions of the pilot. It does not describe what to do if the pilot's actions are incorrect.

The information in this knowledge base has been gathered from two official F16 manuals and the user manual of the flight simulator Falcon 4. Although this flight simulator is a commercial game it is still very realistic and gives a good idea of the situations a real F16 pilot has to deal with and the actions that can be performed by an F16 fighter pilot.

There are a number of versions of the F16. There are the F16A, F16B, F16C and the F16D. The F16A and F16C are one person fighters, while the F16B and F16D are two person aircrafts that are mainly used for training missions. The main difference between the first two versions (the F16A and F16B) and the last two versions (the F16C and F16D) is that the radar system was upgraded. This effects the nonvisual A-G attacks the most. Some of the countries that have bought F16's have made adjustments of their own, an example is the Mid Life Update program that was performed in a lot of European countries in the late seventies. In this MLU program the F16A's were upgraded to resemble the F16C's. Because of all the differences between the different versions a choice had to be made what type of F16 would be modelled for this knowledge base. Because the flight simulator Falcon 4 was based on the F16C and the European F16's that participated in the MLU program are now very similar to the F16C it was decided that the knowledge would be based on the F16C. From here on if we refer to the F16 we mean the F16C.

1.2 Contents

This document has been structured as follows. Chapter 2 describes in what form the data will be stored in the knowledge base. It specifies what kind of rules will be present in the knowledge base and how those rules are presented in this document in a readable form. Besides that, it also gives a possible basic structure for a rule handling and reasoning mechanism that could be used. In chapter 3 the situations that will be described in the knowledge base are given and a short description of the situations is presented. That chapter also contains a state diagram that describes the relationships between the situations. In chapter 4 an explanation is given why the knowledge base has been translated to an XML format and the XML format itself is discussed. Then in the appendices the knowledge base is given in tabular form (appendix A) and in an XML file (appendix B). Appendix C describes all controls that are mentioned in the knowledge base and finally in appendix D an explanation of all the abbreviations that are used is given.

1.3 Acknowledgements

First of all I want to thank my supervisor drs. dr. Leon Rothkrantz for his advice and support during the creation of this document. Furthermore I would like to thank Patrick Ehlert for his help and critical notes, which have contributed greatly to the quality of this report. I would also like to thank Harry Bohnen and Fulco van Westrenen of the National Aerospace Laboratory NLR for sharing their knowledge about flying an F16.

Chapter 2

The structure of the knowledge base

2.1 General

The knowledge base will be divided in a number of situations that we want to be able to recognize, e.g. taking off, taking evasive actions or a dogfight. These situations are given in chapter 3. For every situation there is a set of rules that state the probability that the situation is occurring depending on the state of the aircraft or the events that are happening. An event can have three sources:

Pilot: Pilot events are actions the pilot is taking, for example a button that he pushes or a switch that he switches.

Aircraft: Aircraft events are changes in the aircraft's state. For example a change in altitude or speed.

Environment: An event from the environment can be a missile that is launched at the aircraft by an enemy SAM site.

Pilot and environment events are usually related to variables that have discrete values whose changes will likely be important. Therefore these values should be monitored constantly so that changes will be detected immediately. Aircraft events are usually related to variables with continuous values that change often and gradually. These continuous values should be sampled at regular intervals.

Next to the events there is another source of information that can be used to determine the current situation. This is the flight plan for the flight. The flight plan contains information about the steerpoints the pilot will fly to during the flight, just like a normal flight plan, but it also contains information about the situations that will occur at those steerpoints. This enables the program to predict what situation should occur at what time. The flight plan is further discussed in sections 3.2 and 4.2.

2.2 The rules

As said before the rules are grouped according to the situation they relate to. Every rule will have a value that says what the probability is that the situation the rule applies to is occurring when the rule is fired. When data is passed to the knowledge base some rules will fire and some will not. A probability calculator will combine all probabilities that are the result of the rules that fire and calculate a new probability for the situation. Thus, depending on the rules that fire the probability that the F16 is in a certain situation will increase or decrease. The probabilities that are stored in the knowledge base are fuzzy values from the following fuzzy set: *VBP (Very Big Positive), BP (Big Positive), MP (Medium Positive), SP (Small Positive), VSP (Very Small Positive)*. The probability calculator will combine all the fuzzy values he gets from the rules and produce one fuzzy value that represents the probability that the situation it belongs to is occurring. How the fuzzy values will be implemented and which combination algorithm should be used is not part of this document, but it could be something like the method described in [5]. Once the probability calculators for every situation have produced a probability, an overall controller will evaluate all those probabilities and determine if it can say with enough certainty that one of the situations is taking place. This process is visualized in figure 2.1.

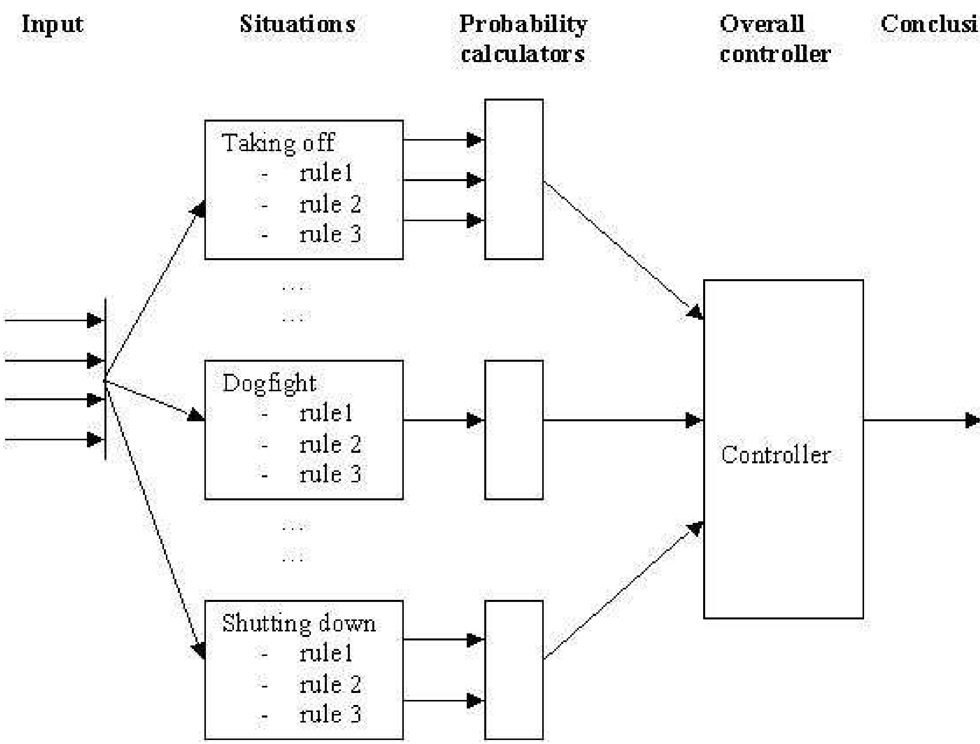

Figure 2.1: Overview of the reasoning process.

For every situation there are several kinds of rules:

Action rules: An action rule is a rule that states that a pilot has to or might perform a certain action during that situation. An action by a pilot always has its effect on a control or instrument of the airplane. For example moving the stick to the front will result in the elevator position becoming negative. An action rule is therefore a rule that states with how much the probability that the situation is taking place will change if at some point in the situation a control or instrument is set to a specific value. An action rule also has a priority value. This priority value does not say anything about the probabilities, but about the importance of the action for the situation it belongs to. The priority values are values between 0 and 1. A priority value below 0.5 means that the action might never be performed during the situation. A priority value of 0.5 or above means that the action is compulsory. A priority value of 1 means that the action is vital for the successful completion of the maneuvre. If the action is compulsory but the control or instrument is never set to the given value during the situation the pilot might have forgotten to perform the action and he might have to be informed about that.

Some situations can be split up into a number of phases which all have a certain set of actions that have to be performed during that phase. The actions that have to be performed in a phase are all time dependent in the sense that they must be performed in a certain chronological order. There are also time independent actins, which are actions that might be performed at any time during the situation. Therefore the set of action rules is split up in parts, one part for every phase and a time independent part. If an action in the time dependent part is performed ”out of turn”, which means it is performed while not all actions that should have been performed earlier have been performed yet, this might result in two things: the probability value of the rule might become smaller and the pilot might have to be informed that he has forgotten to do something.

Visual check rules: A visual check rule states that the pilot should check a certain instrument during the situation. These rules may be used if a gaze tracking device is used to observe the pilot during the flight. If the system detects that a certain situation is occurring and the pilot forgets to check an instrument while the value of the system belonging to that instrument is invalid for the detected situation the system could give the pilot a hint that he should check the instrument.

Conditional rules: The conditional rules can be used to determine if a situation has started or if a situation has finished. These rules apply to the same controls or instruments as the action rules. For each control or instrument there are at most two conditions. One condition defining the value the control or instrument should have at the start of the situation and one condition that states what value the control or instrument will have at the end of the situation. The set of start and end conditions actually forms one rule that says that if the given controls and instruments have the given values the probability that the situation has started or ended has a certain value. These probability values are predetermined. The end rule can only fire if at some time in the past the system has detected the start of the situation. Also the action rules for a situation can only fire if the start conditions have been met, but the end conditions have not yet been met.

Additional rules: Additional rules are rules that do not fall under one of the other categories, e.g. rules that specify maximum or minimum values a control or instrument can have during a situation. They might also say something about actions that should not be performed during a situation and how much the probability will decrease if such an action is performed.

2.3 Representation

Because this document only describes the knowledge base and does not give an implementation of the knowledge base in a specific language the knowledge will be described in this document in a generic tabular form in appendix A. These tables make it easy to get an idea of the knowledge in the knowledge base, but it is not straightforward to translate the information in these tables to formal if-then rules. Therefore we have also created a representation in XML format. The format of the XML data will be described in chapter 4.

For the action rules there is one table with four columns that is split up in one or more parts. In the first column of the action tables is the name of the control or instrument of which the value changes due to the pilot's action, the second column is for the new value of that control or instrument, in the third column the priority value of the action is given and the fourth column contains a number that indicates how much the probability for the situation will rise if that action is performed. The priority value gives an indication of the importance of the action during the situation. Lowering the landing gear during landing is a lot more important than checking if there are faults, for example. If there is a part called time independent, the actions in this part may be performed at any time during the situation. The other actions in the table must be performed in the order in which they occur in the table.

For the visual check rules there is a table with a single column in which the name of the instrument the pilot should check is written.

The constraint rules are described by a table with three columns: the name of the control or instrument, the value that control or instrument should have when the situation starts and the value that control or instrument should have when the situation is finished. These start and end values may be empty. Next to the table with all start and end conditions there are two values that indicate the probability that the situation has started or finished if all the start or end conditions have been met.

The additional rules can not be put in one of the tables and are described in normal text. Because the rules can not be decribed in tables they also have not been included in the XML file. The additional rules will have to be implemented separately in the eventual reasoning program.

2.4 The values

The values of the controls and instruments in the action and conditional rules might be a range of values. This is indicated with the mathematical symbols < (smaller than) and > (bigger than). Furthermore it is possible that a control or instrument can have more than one value or it might be that a control or instrument should **not** have one or more values. This is indicated with the logical operators | (OR), & (AND) and ! (NOT). The operator | is used for controls or instruments that may have more than one value, ! is used for controls or instruments that are not supposed to have a certain value and & is used together with the ! operator if there is more than one value that a control or instrument is not supposed to have. For example look at the following table.

Name	**Start**	**End**
ground speed	< 20	0
FCR	!OFF & !STBY	OFF | STBY

In this table it says that the ground speed at the start of the situation should be smaller than the maximum taxi speed, which is 20 knots. Furthermore it says that the FCR may not be off or in the standby mode at the start of the situation, but it has to be in one of these modes at the end of the situation.

Chapter 3

The situations

3.1 Overview

In this chapter all the situations that we will want to recognize are described. In describing the situations a lot of terms and abbreviations are used that may be unknown to most people. Therefore all abbreviations and terms used in this document are explained in appendices C and D.

The following situations will be described by the knowledge base:

- Startup
- Taxiing to runway
- Taking off
- Aborting takeoff
- Normal flight
- Dogfight
- Visual attack
- Nonvisual attack
- Guided attack
- HARM attack
- Taking evasive action
- Deep stall
- Air refueling
- Normal landing
- Flame out landing
- Aborting landing
- Taxiing from runway
- Shutting down

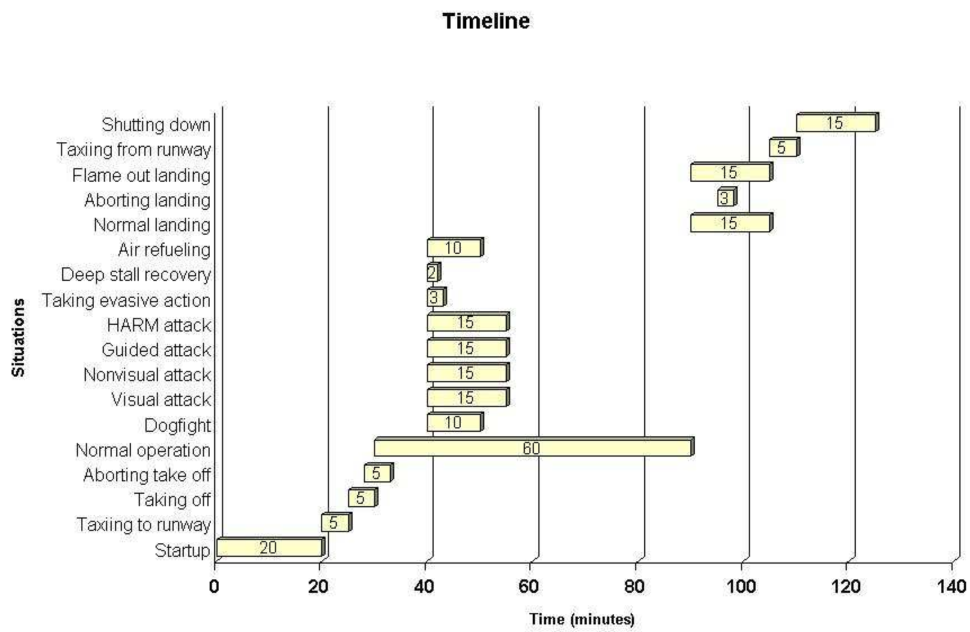

Figure 3.1: The timeline with all possible situations.

3.2 The flight plan

There is a chronological order in the situations; this means that some of the situations can only occur when another situation has finished. This is illustrated in figure 3.1. In this figure all situations have been plotted against the time. The situations after taking off and before landing are situations that can occur in random order. It should be noted that the situations taking evasive action and deep stall can be nested situations and could occur during another situation. These are the only situations that can coexist with another situation. They can both occur during an air to air or air to ground attack while the deep stall situation can also occur during a normal flight or even when the pilot is taking evasive actions. All other situations are mutually exclusive. We'll call the duration of a situation from now on the time window of that situation. The time window is the maximum possible duration of a situation. This is stored in the knowledge base so that only the actions and events that might be relevant for the given situation are evaluated. It would not be logical to log all events and actions of the past hour for detecting a takeoff situation if the takeoff situation will never take more than 10 minutes. To further clarify the chronological order of the situations and the transitions from one situation to another a state diagram has been created and is included as figure 3.2.

The order in which the situations may occur that is given here is an order that always applies for all flights. But when an F16 pilot is on a mission he will have a flight plan that he should follow and that specifies the steerpoints he has to fly to and the actions he has to take at those steerpoints. Such a flight plan can be used to determine before the flight starts in which order some of the situations will occur. This way the system can predict the situations that will come and will be able to check that predicted situation

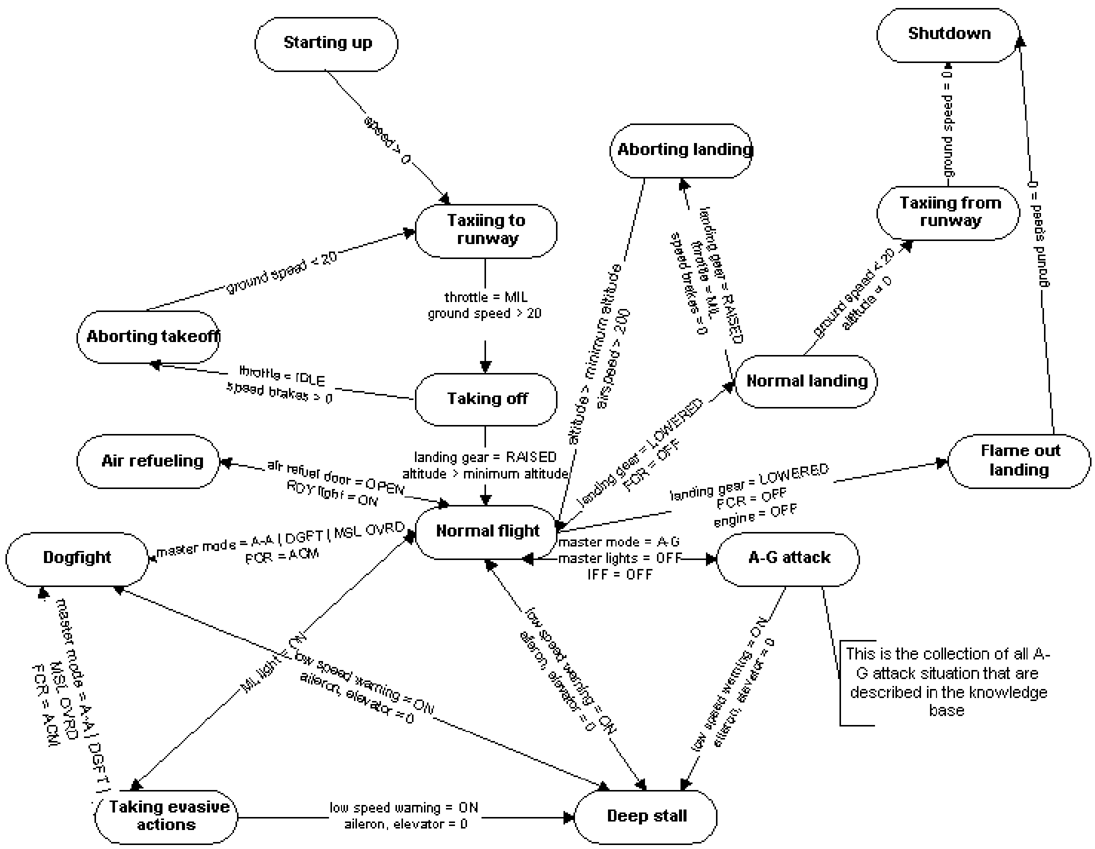

Figure 3.2: A state diagram describing the situations and their transitions.

with the situation it detects itself. This can be an important aid in detecting the current situation. To make it possible to test the knowledge base with a flight plan a generic XML schema has been created that provides a basic structure for defining a flight plan. This XML schema is explained in detail in section 4.2.

3.3 Descriptions

3.3.1 Startup

Startup will be the phase in which the program starts. This is because the pilot will switch on the main power during the startup which should also power up the program. During startup the pilot has to make sure the airplane is ready for takeoff. He has to check all the systems and configure the aircraft for the mission he is going to fly. He will also have to input mission specific data like steerpoints, IP's, RP's and target information. The data that will be stored in the knowledge base for this situation primarily describes the state the airplane should have at the end of the situation. This state can then be checked when the pilot starts taxiing to see if the pilot has forgotten something during the startup.

3.3.2 Taxiing to runway

During this phase the pilot rides the airplane to the runway which he will take off from. This is considered a different situation than taxiing from the runway after the pilot has landed, because the start and end states are switched. The state of the airplane at the beginning of this phase should be equal to the state of the airplane after startup, with the exception of the NWS (Nose Wheel Steering). This is because the pilot has to activate the NWS to be able to taxi safely, so the NWS will be switched on before taxiing starts.

Taxiing is assumed to be finished when the aircraft comes to a halt. It is assumed the pilot will not halt the airplane between the ramp and the start of the runway. This is a reasonable assumption because the pilot usually has only a limited amount of time for takeoff. The flight controllers generally want to get the airplanes in the air as fast as possible. Therefore it is also assumed that if the pilot arrives at the runway and is cleared for takeoff by the tower he is not required to hold short and can enter the runway immediately. However once on the runway he will have to halt to make a final check of his systems. This is why taxiing can still be considered to be finished when the aircraft comes to a halt.

3.3.3 Taking off

This situation comes immediately after taxiing to the runway. It starts with an airspeed of zero, because the pilot will stop at the start of the runway to make a final check of the systems. The program will have a very good indication that the takeoff has started when the ground speed exceeds the maximum taxi speed. If a minimum altitude has been set on the A-LOW page of the DED and the f16 climbs above that minimum altitude then the takeoff phase can be considered to be ended once all actions in the action list have been performed.

Aborting a takeoff can only be done when taking off has already started and before it has finished. Therefore the aborting takeoff situation is a nested situation. When the system detects that the takeoff is being aborted it will consider the taking off situation to be finished.

3.3.4 Aborting takeoff

A takeoff can be aborted for various reasons. It is assumed that a takeoff can only be aborted when the airplane is still on the ground. If it is already in the air there will probably not be enough runway left to stop the aircraft. When the takeoff is aborted the throttle is set to IDLE, the speed brakes are extended and if the speed is bigger than the maximum wheel brake speed the wheel brakes are used too. The pitch angle should be kept around 7 degrees because that will create drag that will help slow down the aircraft. Depending on the reason the takeoff was aborted the procedure taxiing from the runway might start after aborting the takeoff.

3.3.5 Normal flight

In the situation normal flight the pilot is flying in friendly territory towards a steerpoint. This is the situation in which the pilot will find himself most of the time. Because this is the standard situation we will assume that if no other situation is detected then there is a big chance that the aircraft is in normal flight. This is implemented by setting the start probability of the normal flight to VBP and the end probability to VSP, although there is only a small amount of start and end conditions. Examples of the conditions are that the altitude must be bigger than the minimum altitude and the master mode must be set to NAV. There are also no real characteristic actions or visual checks the pilot should perform in this situation. When the start probability of another situation becomes high enough the normal flight situation will be considered to be finished.

3.3.6 Dogfight

When the pilot is engaged with an enemy fighter his survival depends on his piloting skills. Although the F16 has a lot of systems to support the pilot, he is still the one that has to make the critical decisions. The attention of the pilot will be mainly directed to the outside environment during a dogfight because he will be trying to keep his eyes on the enemy fighter. For these reasons care should be taken not to give the pilot useless information or information that could distract him during a dogfight. The main characteristics by which a dogfight can be recognized are the combination of the master arm switch, the master mode and the selected weapon. If the master mode is set to A-A, the master arm to MASTER ARM and an A-A missile has been selected this is a good indication that the pilot is in a dogfight. Furthermore, in a dogfight the pilot will release chaff and flare on a regular basis to deflect missiles he might not have detected.

3.3.7 Visual attack

A visual attack is an attack on a ground target which the pilot can see with the naked eye. The following kinds of attacks are all visual attacks:

The strafe attack: this is an attack with the A-G gun. In this attack the pilot keeps the gun pipper pointed at the target while firing the gun.

A rockets attack: This attack is very much like a strafe attack with the A-G gun, but in this attack the pilot uses rockets, which do more damage, but are slower than the bullets of the gun and are less accurate.

A CCIP (Continuously Computed Impact Point) attack: When the pilot selects the CCIP delivery mode on the SMS (Stores Management System) page the CCIP pipper will appear in the HUD. This is a circle under the FPM (Flight Path Marker) that is connected to the FPM by a straight line as in figure 3.3. The pilot positions the FPM above the target and lets the CCIP pipper approach the target. When the pipper reaches the target the pilot should pickle and the bombs will be released. It is possible that the impact point is not visible in the HUD FOV, for example because it is under the nose of the airplane. In this case a horizontal tick line (the delay cue) will appear on the line connecting the FPM to the TD (Target Designate) box. When the pipper reaches the target the pilot should press the pickle button and keep it depressed. After the pickle button is depressed the HUD symbology will change to something very similar to the post-designate symbology of the DTOS attack (see the next paragraph). There will be a vertical steering line with a horizontal solution cue on it. When the FPM reaches the solution cue the bombs will be released and the FPM will flash to indicate this release. After the bombs are released the pilot can release the pickle button. The time the special HUD symbology is displayed might be very short, it might be less than a second.

The DTOS (Dive Toss) attack: For a DTOS attack the DTOS delivery mode should be chosen. The initial HUD symbology for the DTOS attack is a TD box around

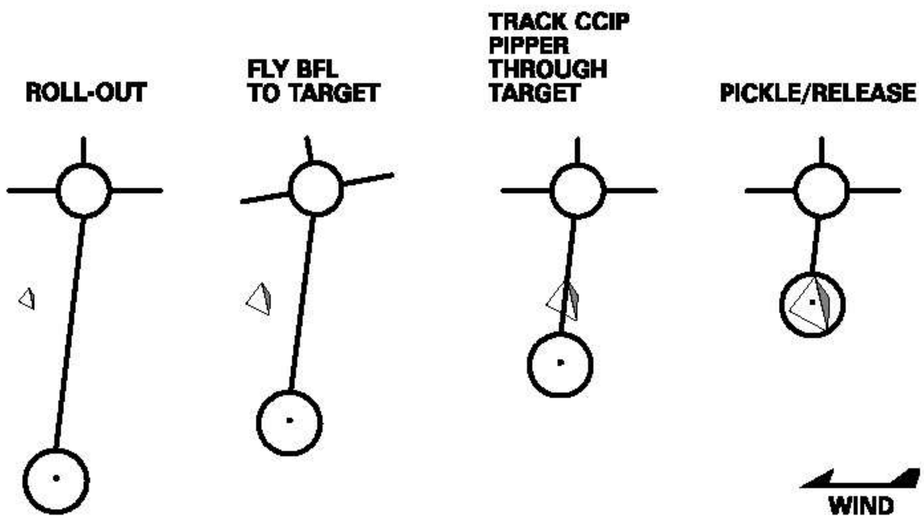

Figure 3.3: The HUD symbology for a CCIP attack.

the FPM (see figure 3.4). When the pilot is on the final leg of the attack (which means he is flying directly towards the target) he dives towards the target. He then designates the target either by pressing and holding the pickle button or by pressing the designate button. Designating the target fixes the TD box on the ground. The pilot can then slew the TD box over the target. Slewing means that the pilot moves the fixation point of the radar. This might be necessary if the TD box is not directly over the target after designating. If the TD box is not directly over the target the FCR might compute the wrong impact point and the bombs might miss the target. After designating the target a vertical line will appear in the HUD going up from the TD box. Somewhere along the line will be a horizontal line. This is the release cue. The pilot should start a smooth pull up after designating the target while keeping the FPM on the vertical line. When the FPM reaches the release cue and the pilot has the pickle button depressed the bombs will release. If the pilot designates with the designate button he must depress the pickle button before the FPM reaches the release cue.

A TARS attack: This is an intelligence gathering attack in which the TARS (Tactical Aerial Reconnaissance System) is used to gather intelligence about a target.

The pilot may do more than one attack run to bomb the target although the pilot should always try to drop all bombs in one run. When the pilot has finished the attack he should switch the master arm to a safe position as soon as possible.

3.3.8 Nonvisual attack

A nonvisual attack is performed using the CCRP (Continuously Computed Release Point), LADD (Low Altitude Drogue Delivery) or BCN (Beacon) delivery method. In

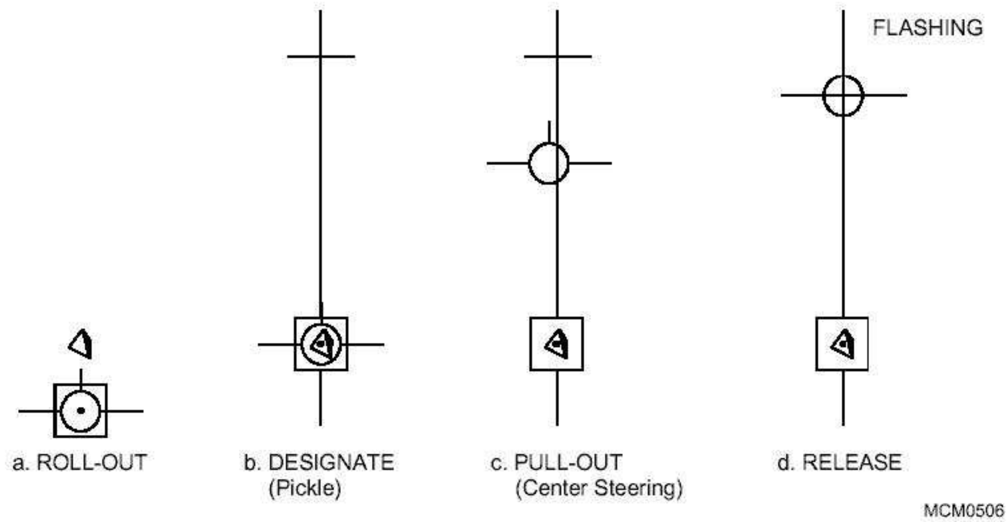

Figure 3.4: The HUD symbology for a DTOS attack.

this last method the target's position is only known relative to a ground-based radar beacon. In the CCRP method the FCC (Fire Control Computer) continuously computes the point at which the bombs should be released. In these methods the pilot should press the pickle button before the release point is reached and keep it depressed until all bombs have been released. The HUD symbology (see figure 3.5) is a vertical line (the steering line) that goes from the bottom to the top of the HUD. The pilot should lock onto a target steerpoint and move the FPM to this line. When the pilot is in range to loft the bomb on the target a horizontal line (the release cue) will appear at the top of the steering line that slowly descends towards the FPM. If the release cue reaches the FPM a loft reticle will appear. The pilot should then press and hold the pickle button. After a few seconds the release cue will reappear at the top of the steering line. In CCRP the pilot now has several options. He can either drop the bombs in a dive, he can drop the bombs in level flight or he can climb and loft the bombs on the target. In LADD the pilot should climb and loft the bombs on the target in a 45 degrees angle. When the FPM reaches the release cue for the second time the bombs will be released and the FPM will flash.

3.3.9 Guided attack

A guided attack is an attack with a laser guided or heat seeking bomb. An example of a heat seeking bomb is the Maverick. There are several kinds of LGB's (Laser Guided Bombs). A special kind of LGB is the GBU (Guided Bomb Unit) which is used by the U.S. Air Force. For these armaments there are two modes that can be used: slave and boresight mode. In slave mode the missiles or bombs are targeted at the steerpoint that is selected with the radar. In boresight this is not the case. In boresight mode the TD box is initially over the FPM and the missiles or bombs can be aimed at a target by pressing the designate button when the TD box is over the target. If that happens the TD box is ground stabilized and can be slewed over the target if necessary.

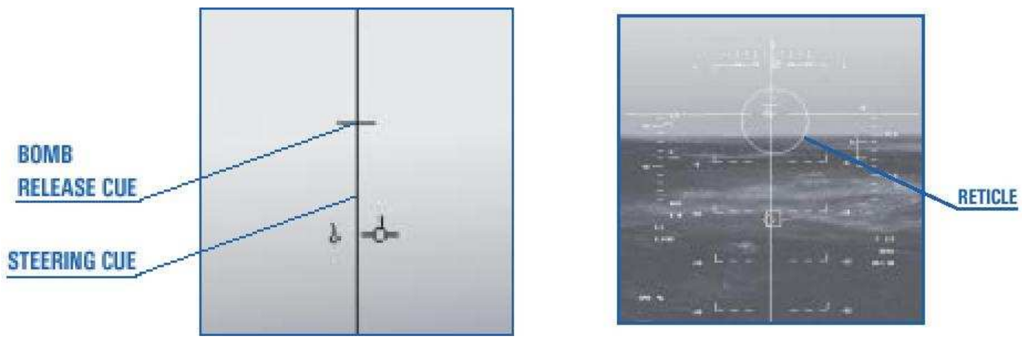

Figure 3.5: The HUD symbology for a CCRP attack.

When the pilot selects a target steerpoint and the Maverick missile or an LGB with one of the MFD's a picture of the place where the missile seeker head is seeking will appear in that MFD. The seeker head will be looking at the place of the TD box. A tracking gate will also be visible in the MFD, which indicates the place the missile is aimed at.

The following procedures apply to these attacks:

Maverick: If the pilot selects a target, either by selecting a target steerpoint in slave mode or by designating a target in boresight mode a picture of the selected target will appear in the MFD. The pilot can slew the tracking gate over the preferred target in the MFD if necessary. If the slave mode is selected the pilot should press the designate button to lock the tracking gate over the target. When the seeker head detects a valid target in the tracking gate, the tracking gate will start to pulse. The pilot should then press the designate button again to lock the Maverick onto the target. From this point on the pilot can fire the Maverick as soon as the target is in range.

LGB: An LGB attack is very similar to a Maverick attack. A picture of the target will also appear in the MFD if a target is selected. However designating the target once the target is selected in slave mode is not recommended in an LGB attack. The HUD symbology for an LGB attack is similar to the CCRP HUD symbology. This CCRP symbology will appear when the slave mode is selected or when the target has been designated in the boresight mode. When the tracking gate starts to pulse over the target the pilot has in contradiction with the Maverick attack the choice to lock up the target or not. The CCRP HUD symbology should be used to determine the moment of release. Another difference with the Maverick attack is that the targeting pod of the LGB has to stay locked on the target until impact, while the pilot can break the lock immediately after release in the Maverick attack.

3.3.10 HARM (High-speed Anti-Radiation Missile) attack

The HARM is specially designed to be used against targets that emit radar waves. For this weapon there is a special radar mode, the HTS (Harm Targeting System) mode. The HTS antenna's detect radar waves. The HTS display shows all objects in its range that are emitting radar waves. The HTS can detect radar emitting objects all around the aircraft. To lock onto a target the pilot has to slew the radar cursors of the HTS over a target and then press the designate button. Once the target is in range the pilot can then fire the HARM by pressing the pickle button. The HARM is a very flexible missile that is able to shoot a target that is located behind the aircraft. However this reduces the missiles range because it will lose a lot of energy in making the turn. It is recommended that the pilot turns the aircraft to aim at the target if that is possible.

3.3.11 Taking evasive action

In this situation the pilot is alerted of an incoming missile by the RWR (Radar Warning Receiver). The RWR is only able to detect radar guided missiles, so heat seeking missiles are not detected and should be spotted by the pilot himself. This situation might be a nested situation of a Dogfight or an A-G attack, but might also be started ”out of the blue” when the pilot is not aware of an enemy aircraft or ground installation until a missile is launched at him.

3.3.12 Air refueling

Air refueling is for most beginning pilots a difficult maneuvre because it requires very precise steering. The tanker is usually found by using the air to air TACAN, but a pilot can also ask an AWACS to guide him to a tanker. Before approaching the tanker the pilot should make sure all systems which emit electrical signals are in standby mode. A tanker usually flies a set pattern in a safe area. It is up to the pilot of the F16 to approach the tanker so that the tanker boom can be connected to the refuel door of the F16. When the pilot has finished refueling he should inform the tanker he wants to disconnect. After the boom operator has disconnected and the boom is well away from the airplane the pilot can continue his mission.

3.3.13 Deep stall

Deep stall is a special kind of stall. A normal stall is a lack of energy from which the pilot can recover by lowering the nose and increasing the throttle. In a deep stall the FLCS (Flight Control System) will take control of the airplane and the pilot will be shut out of the control loop. The airplane will be falling down with a bobbing nose and the AOA pegged at 30 degrees if the airplane is upright or at -5 degrees if the airplane is inverted. If the airplane is inverted it will also be spinning around. The FLCS will compensate for the spinning if the airplane is upright. Just lowering the nose will not help in a deep stall. The following actions should be taken to get out of a deep stall:

- **Release controls:** By releasing the controls the pilot gives the airplane the chance to self-recover.
- **Throttle to idle.**
- **Set rudder in opposite yaw direction:** This is only necessary if the airplane is inverted and spinning. The rudder should be used to try to stop the spinning.
- **Switch the MPO:** By switching the MPO (Manual Pitch Override) to OVERRIDE the pilot overrides the FLCS and regains control of the flight controls.
- **Cycle in phase:** The nose of the airplane will be going up and down. The pilot should now take the controls and try to get in phase with this bobbing. So when the nose comes up the pilot should pull (if the airplane is upright) and when the nose goes down he should push. The pilot will know he is out of the deep stall if

the nose stays below the horizon and does not try to come up again. At this point the pilot should keep the nose down and increase speed until he has reached 200 knots.

3.3.14 Landing

The F16 already has a system that tries to detect when the pilot is trying to land the airplane. This detection is based on the angle of attack and the airspeed of the airplane. When the airplane detects the pilot is trying to land it will give hints as to whether the pitch angle is good or that the pilot should lift or lower the nose. This built in detection system is easily misguided, it might also think the pilot is landing when he is trying to make a slow turn for example. Still this system can be used as an indication the pilot might be trying to land the airplane. The most important indication that the pilot is landing the airplane is of course when he lowers the landing gear. Landing is considered to be finished if the airplane is on the ground and the ground speed is less than the maximum taxi speed. The procedures for an emergency landing are practically the same with the exception that the pilot will jettison the stores when he is making an emergency landing and lower the hook. The hook is also lowered when landing on an aircraft carrier.

3.3.15 Aborting a landing

A landing can only be aborted when one has begun. Aborting a landing in an F16 is no different from aborting a landing in another airplane. The main actions are raising the landing gear if they have been lowered, closing of the speed brakes and setting the throttle to military power or afterburner.

3.3.16 Flame-Out landing

A flameout landing is a special kind of emergency landing. A flameout landing is a landing with no engines. If the engines of an F16 shut down the pilot can try to glide to a nearby airfield to land the F16. The F16 is capable of covering 1 NM (Nautical Mile) for every 1000 feet altitude, depending on wind and aircraft configuration (weight and drag). If the EPU is switched on the FPM will take these factors into account and the pilot can determine whether he will make it to the airfield or not by looking at the position of the FPM relative to the airfield. If the FPM is short the pilot will not make it and should consider ejecting, if it is long the airplane has got more than enough energy to make it to the runway. The pilot should try to maintain the optimum glide speed during the landing to cover as much distance as possible. It is impossible to correct a shortage of energy while an excess of energy can be corrected easily using the speed brakes.

3.3.17 Taxiing from runway

When the pilot has finally landed he will taxi from the runway. This phase starts when landing has ended and the ground speed is below the maximum taxi speed. The situation ends when the ground speed is zero and parking brakes have been set. Nose wheel steering has to be on during taxiing. During taxiing the pilot might already start shutting down some systems.

3.3.18 Shutting down

This is the phase in which the pilot shuts down all systems. The most important information of this phase is the end state of the airplane, so that the system may be able to check if the pilot has not forgotten to shut down a system.

Chapter 4

The knowledge base in XML

4.1 General

As said before the knowledge base will be stored in an XML file. XML is a tag based language for structured documents or data. It is not a way to represent data like HTML, although it could be used that way. XML is described on the official XML website of the World Wide Web Consortium ([6]) by ten points:

1. XML is for structuring data.
2. XML looks a bit like HTML.
3. XML is text, but isn't meant to be read.
4. XML is verbose by design.
5. XML is a family of technologies. XML has been extended by a lot of people with all kinds of modules, which makes XML very powerful.
6. XML is new, but not that new.
7. XML leads HTML to XHTML.
8. XML is modular.
9. XML is the basis for RDF (Resource Description Framework) and the semantic web. RDF is an XML text format that supports resource description and metadata applications.
10. XML is license-free, platform-independent and well-supported.

After all data that should go into the knowledge base had been selected it had to be put into a form that could be used by a program to reason with the knowledge. We considered languages like CLISP and JESS, but eventually chose for XML for the following reasons:

- XML is a widely accepted standard.
- XML is easier to read than a list of rules.
- XML is very well supported.

- If the knowledge base is written in XML it can easily be extended.
- With XML it is possible to define a DTD (Data Type Definition) or a schema that defines the structure the XML file should have so that future knowledge bases for other aircrafts will have the same generic form.
- XML data can easily be translated to another desired format like CLISP or JESS.
- It is easy to write a program to translate the XML data to if-then rules. This way we will be able to generate a lot of rules from just a few lines of XML code.

The structure of the XML file will have to be very well defined so that flying with other airplanes can be described in the same way as we have done for the F16. The ideal situation would be that one program could be written that detects the current situation in a flight and that that program can be used for different airplanes if a different XML file is used as the knowledge base. We have tried to achieve this by specifying the structure the XML file should have in an XML schema.

4.2 The schema for a flight plan

As explained in section 3.2 an XML schema has been created for defining a flight plan. This flight plan can then be used to help determine the current situation in a flight. The flight plan schema has been made independent of the aircraft with which the flight is flown, just like the XML flight schema. An XML file of a flight plan will have the following structure:

- flightplan
    - steerpoint
        - heading
        - altitude
        - TOS (Time Over Steerpoint)
        - action
    - steerpoint

      .

      .

The information that is stored about a steerpoint is the heading that should be flown towards the steerpoint, the altitude at which the pilot should fly over the steerpoint and the time at which the pilot should reach the steerpoint (TOS). This is all standard information that is also present in real flight plans, however what can also be added in this flight plan is the actions a pilot will perform at the steerpoint. These actions are one or more of the situations that are described in chapter 3. If there are more than one actions to be performed at a steerpoint then the actions specified at the steerpoints should be in chronological order, so the first action in the XML file should be performed first, then the second and so on. Next to this information the type of the steerpoint will be specified and the steerpoint will get a number that specifies the order of the steerpoints. A steerpoint can be of one of the following types:

STPT: This is a navigational steerpoint.

IP: This is the steerpoint for an initial point. The initial point is the point where the pilot will climb to attack altitude and position himself for the final attack run.

TGT: TGT is the steerpoint type for a target steerpoint. This is usually a ground target and this steerpoint will usually contain an action with the name of the situation of one of the A-G attacks.

The complete XML flight plan schema and an example of an XML file describing a flight plan can be found in appendix B.1.

4.3 The XML flight schema

There are several ways in which we can define the structure to which the XML files for different airplanes must conform. We can use either a DTD or an XML schema. The DTD is older than the XML schemas and therefore has less functionality and is less flexible. It is on the other hand much easier to understand and implement. Although we could use the DTD because the form in which we will store the data in the knowledge base is not too complex, it will make the knowledge base much more flexible and easier to expand if an XML schema is used to define the structure. Therefore we have chosen to use an XML schema. The complete XML schema is given in appendix B.2.

4.3.1 XML specific considerations

When creating an XML file it is often not clear when to use an element to denote information and when to use an attribute. For example the following pieces of XML all contain the same information:

```
<tag name="test">
     <child name="child1">10</child>
     <child name="child2">1</child>
</tag>

<test>
     <child name="child1" value="10" />
     <child name="child2" value="1" />
</test>

<test>
     <child1>10</child1>
     <child2>1</child2>
</test>
```

In the first example `tag` and `child` are the elements and `name` and value are attributes. In the second example the `tag` element has been replaced by a `test` element. These two elements contain the same information. Finally in the third example the `child` element has been split into two different child elements.

There are no clearly defined rules that say when to use an attribute and when to use an element, it often depends on the kind of information and the intention of the author of the XML file. Our main consideration in deciding whether to use elements or attributes is the generality of our XML schema. To make our XML schema usable for other aircrafts our tags can not be too specific and we will have to put a lot of information in the attributes. To illustrate this, imagine we would use a different tag for every possible action the pilot can perform, then we would have a tag for designating a target (<designate>). But this tag would never be used in a knowledge base for a Cessna or a passenger airplane for example. Besides, actions that can be performed in other airplanes, but not in an F16 would have to be added to the schema. Therefore we will mainly use very generic elements with attributes to specify the meaning of the elements.

4.3.2 The hierarchy

The hierarchical structure of the XML file as it is defined in the XML schema is the following:

- flight
    - situation
        - actions
            - phase
                - action

                  .

                  .

                .

                .
        - visual checks
            - instrument

              .

              .
        - constraints
            - constraint

              .

              .
    - situation

      .

      .

Every element in this hierarchy will be a tag that can be put in the XML file. The tags all have some metadata and a certain meaning.

flight: The flight tag is the root tag of the XML document. It contains the name of the airplane for which the knowledge base has been created.

situation: For every situation there is a separate tag with the name of the situation in it. It also has an attribute that contains the timewindow of the situation.

actions: This tag is the parent tag of the set of action rules for the situation.

phase: This tag is the parent of all actions that are part of a phase in the situation. It has an attribute containing the name of the phase. The actions that are the children of this phase tag should usually be performed in the order in which they occur in the xml file, so the first action of the first phase should be performed first, then the second action of the first phase, etc., until all actions of the first phase have been performed after which the actions of the second phase should be performed and so on. The exceptions are action tags that are children of the phase tag with the name "time independent". These actions can occur at any time during the situation in random order.

action: This tag defines an action rule for the situation. It contains the name of the control or instrument, the priority value and the fuzzy probability value as attributes. The value of the element is the value the control or instrument will get when the action is performed.

visual checks: This tag is the parent tag for all the instruments that the pilot should visually check during the situation.

instrument: This tag is a tag for an instrument that the pilot should check during the situation. For now this tag only contains the name of the instrument, but in the future this might be extended so that it also contains information for a gaze tracker about the position of the instrument in the cockpit.

constraints: The constraints tag is the parent tag for all start and end constraints on controls and instruments for a situation. It has two attributes with fuzzy probability values. These are the probability values for the start and end rules.

constraint: This tag contains information about the value a control or instrument will have at the start and/or end of the situation. It contains a name attribute with the name of the control or instrument, a start attribute with the value the control or instrument should have at the start of the situation and an end attribute with the value the control or instrument should have at the end of the situation.

4.3.3 The values

A lot of the values that will be stored in the knowledge base represent positions of switches and buttons in the cockpit. The easiest way to represent these values for a computer program is with numbers (e.g. the ON position will get the value 1 and the OFF position will get the value 0). These numbers are not easy to interpret for human readers however and since we want the XML file to be readable such values will be represented by variables. In a DTD it is possible to define variables the can be referenced in the XML file and that represent a value. The ON and OFF positions could for example be defined as:

```
<!ENTITY ON "1">
<!ENTITY OFF "0">
```

They could then be referenced in the XML file by putting the name of the variable between a "&" and a ";" (e.g. &ON;). When a parser reads the XML file all variables will be replaced by their values. The variables will be defined in a separate file so that they can easily be changed. This file will then be specified in the XML file as the DTD for the XML file. For further information about the values see section 2.4.

Chapter 5

Conclusions and future work

When it was decided to create a knowledge base that would describe the situations an F16 fighter pilot might encounter, it was not clear if enough knowledge about the subject would be publicly available. But from the official F16 manuals and the Falcon 4 user manual and with help of the NLR a lot of knowledge could be gathered. Still a lot of questions remained unanswered, either because the answers were confidential or because no person with that specific knowledge could be found. But despite those limitations the impression has grown during the creation of the knowledge base, that the amount and detail of the information that could be gathered is enough to build a prototype system for analyzing the current situation. And even if the knowledge in the knowledge base turns out not to be sufficient for building a system for analyzing a flight with an F16, the framework that was used to create the knowledge base can still be used for building a similar knowledge base for other airplanes. This also applies to the model of the reasoning process to detect the current situation that is suggested in this document.

Recommended future work is converting the xml format of the knowledge base to a format that can be used by an implementation language (for example CLISP) and writing a program that reasons with the knowledge and determines which situation the pilot is in. This could be done with the knowledge base that is described in this document or with a simpler knowledge base for a Cessna or something like that. If in such a project a gaze tracker is used it is recommended that the knowledge base is extended, because the information about visual checks given in this knowledge base is very basic and not very detailed. Information like the priority or importance of the check, the value that the instrument should have when the pilot checks the instrument or the location of the instrument in coordinates that correspond with the gaze tracker coordinates could also be stored in the knowledge base. Furthermore it might be necessary to add more time constraint to the situations. The timewindows given in section 3.2 are maximum values for the entire situation. One can imagine that it would be desirable to know the timewindow of a specific phase in a situation to be able to draw conclusions about the pilot's behavior. But the knowledge base as it is now should contain sufficient information for detecting the current situation an F16 fighter pilot is in.

Appendix A

The knowledge base described in tables

A.1 Startup

The actions

Name	**Value**	**Priority**	**Probability**
startup			
parking brakes	ON	1	MP
throttle	MIL	0.8	VSP
throttle	IDLE	1	VSP
JFS	START2	1	BP
throttle idle detent	1	1	BP
INS	ALIGN NORM	1	BP
time independent			
air refuel door	OPEN	0/0.7*	SP
air refuel door	CLOSED	0/1*	SP
HUD	ON	0.9	MP
landing light	ON	0.8	SP
ejection seat	ARMED	0.8	BP
F-ACK	1	0.5	VSP
A-LOW	1	0.5	VSP

$*$ These are compulsory on missions with air refueling and have on those missions a higher priority.

The visual checks

Instrument
HUD
speed brakes
wheel brakes
U/C
DED
MFD
fuel flow
HYD oil light
RDY light*
DISC light*
AR/NWS light*

∗ Should only be checked on missions with air refueling.

The conditions

Start probability: MP.
End probability: BP.

Name	Start	End
landing gear	LOWERED	LOWERED
master mode	-	NAV
master arm	-	AUTO
master fuel	-	ON
fuel pumps	-	NORM
parking brakes	-	ON
radio	-	7
A/C lights	-	ON
landing lights	-	ON
master lights	-	NORM
FCR	-	NO RAD
RALT	-	!OFF
TACAN function	-	TR
air source	-	NORM
ejection seat	DISARMED	ARMED
JFS	-	OFF
INS	-	NAV
ECM	-	OFF
MFD	-	!OFF
FCC	-	ON
SMS	-	ON
UFC	-	ON
GPS	-	ON
DL	-	ON
HUD	-	ON
EWS JMR	-	ON
EWS CHAFF	-	ON
EWS FLARE	-	ON
EWS PWR	-	ON
elevator trim	-	0
rudder trim	-	0
ground speed	0	0
altitude	0	0

Additional rules

The following additional rules apply to this phase:

- Altitude, roll, pitch and ground speed should remain zero during the entire startup.

A.2 Taxiing to runway

The actions

Name	Value	Priority	Probability
taxiing			
parking brakes	OFF	1	MP
throttle	>IDLE	1	SP
throttle	IDLE	1	SP
wheel brakes	ON	1	MP
time independent			
wheel brakes*	ON	0.6	MP
MPO	NORMAL	1	MP

∗ The pilot should always test the wheel brakes when he's taxiing to the runway.

The visual checks

Instrument
speed brakes
caution panel
DED
fuel
fuel flow
wheel brakes
master arm

The conditions

Start probability: MP.
End probability: BP.

Name	Start	End
parking brakes	ON	OFF
wheel brakes	OFF	ON
speed brakes	-	>0
NWS	ON	ON
landing gear	LOWERED	LOWERED
ground speed	0	0
throttle	IDLE	IDLE
altitude	0	0
pitch	0	0
roll	0	0
MPO	-	NORMAL
radio	7	7
master arm	AUTO	AUTO

Additional rules

The following additional rules apply to this phase:

- Altitude, roll, pitch, rudder trim and elevator trim will remain zero during taxiing.

- Ground speed should never exceed maximum taxi speed, which is 20 knots.

A.3 Taking off

The actions

Name	**Value**	**Priority**	**Probability**
grounded			
speed brakes	0	0.8	VSP
throttle	>IDLE	1	VSP
wheel brakes	OFF	1	SP
throttle	MAX AB	0	SP
elevator	>0	1	VSP
airborne			
landing gear	RAISED	1	VBP
FCR	!NO RAD	0.7	VSP
time independent			
F-ACK	1	0.5	VSP

The visual checks

Instrument
HUD
master arm
caution panel
radio
DED
speed brakes
U/C
AR/NWS light
MFD

The conditions

Start probability: SP.
End probability: VBP.

Name	**Start**	**End**
speed brakes	1	0
ground speed	0	>0
NWS	-	OFF
throttle	IDLE	>IDLE
rudder	0	-
rudder trim	0	-
altitude	0	> min. altitude*
pitch	0	-
climbing rate	0	-
radio	7	-
FCR	NO RAD	!NO RAD

∗ This only applies if a minimum altitude has been set in the A-LOW page of the DED.

Additional rules

The following additional rules apply to this phase:

- Pitch should not exceed 14 degrees.
- Altitude will remain zero during the grounded phase.
- Altitude will be bigger than zero in the airborne phase.

A.4 Aborting takeoff

The actions

Name	**Value**	**Priority**	**Probability**
aborting			
throttle	IDLE	1	BP
speed brakes	1	1	BP
wheel brakes	ON	0*	BP
hook	LOWERED	0	BP

∗ Wheel brakes do not have a high priority because it might be possible to slow down sufficiently without them.

The visual checks

Instrument
HUD
DED
caution panel

The conditions

Start probability: VSP.
End probability: VBP.

Name	**Start**	**End**
speed brakes	0	1
wheel brakes	OFF	ON
altitude	0	0
throttle	>IDLE	IDLE
ground speed	>0	0

Additional rules

The following additional rules apply to this phase:

- The altitude of the aircraft will stay zero during the entire situation.
- The pitch angle while aborting a takeoff should be around 7 degrees.

A.5 Normal flight

The visual checks

Instrument
HUD
MFD

The conditions

Start probability: VBP.
End probability: VSP.

Name	**Start**	**End**
master mode	NAV	-
master arm	OFF	-
master lights	ON	-
landing gear	RAISED	RAISED
wheel brakes	OFF	OFF

Additional rules

The following additional rules apply to this situation:

- The altitude should stay above the minimum altitude during the entire situation.
- If the master arm switch is set to a non safe position this situation is considered to be finished.
- If the start of another situation is detected this situation is considered to be finished.
- If no other situation is detected and all start conditions of this situation have been met then this situation is considered to have started.
- If a minimum altitude has been set on the A-LOW page the altitude should always stay above that minimum altitude.

A.6 Dogfight

The actions

Name	Value	Priority	Probability
ingress			
FCR	ACM	0/1*	VSP
SMS	AAM	1	MP
ECM	ON	0.9	VSP
engage			
master arm	MASTER ARM	1	BP
pickle	1	0.4	BP
pickle	0	0/1**	BP
egress			
master arm	AUTO	1	VSP
master mode	NAV	0.7	VSP
FCR	SLW | RWS	0	VSP
master lights	NORM	0.6	SP
time independent			
chaff/flares	1	0.4	MP
throttle	MAX AB	0	SP
F-ACK	1	0.5	VSP

∗ Missiles like the AIM-9 may be fired without a radar lock and radar might spike an unaware bandit.
∗∗ Releasing the pickle button is compulsory when the pickle button has been depressed during the dogfight.

The visual checks

Instrument
HUD
radio
caution panel
MFD
DED

The conditions

Start probability: SP.
End probability: BP.

Name	Start	End
RWR	ON	-
IFF	OFF	-
EWS mode	!OFF & !STBY	-
master mode	A-A | DGFT | MSL OVRD	NAV
master arm	OFF	AUTO
master lights	OFF	NORM
FCR	ACM	-
landing gear	RAISED	RAISED
wheel brakes	OFF	OFF
ATT/FPM switch	FPM	-

A.7 Visual attack

The actions

Name	Value	Priority	Probability
ingress			
designate	1	0.3	MP
slew	1	0	MP
engage			
master arm	MASTER ARM	1	VBP
elevator*	<0	0.4	VSP
pickle / fire gun	1	0.4	BP
pickle / fire gun	0	0/1**	BP
egress			
elevator	>0	0.4	VSP
master arm	OFF	1	BP
time independent			
A-LOW	1	0.5	VSP
F-ACK	1	0.5	VSP

∗ This is done to keep the gun on the target and concentrate the fire. It is done mainly for strafe attacks.
∗∗ Releasing the pickle button is compulsory when the pickle button has been depressed.

The visual checks

Instrument
HUD
DED
MFD
caution panel

The conditions

Start probability: MP.
End probability: MP.

Name	Start	End
master mode	A-G	!A-G
master arm	OFF	OFF
steerpoint type	TGT | IP	-
IFF	OFF	-
EWS mode	!OFF & !STBY	-
RWR	ON	-
SMS	A-G Gun | RCKT | CCIP | DTOS | TARS	-
FCR	A-G	-
pickle	0	0
master lights	OFF	NORM
landing gear	RAISED	RAISED
wheel brakes	OFF	OFF
ATT/FPM switch	FPM	-

Additional rules

The following additional rules apply to this situation:

- The maximum airspeed for performing an A-G attack is 0.95 MACH.
- The altitude should always stay above the minimum release altitude of the chosen armament.

A.8 Nonvisual attack

The actions

Name	Value	Priority	Probability
	ingress		
designate	1	0.3*	MP
designate	1	0*	MP
slew	1	0	MP
	engage		
master arm	MASTER ARM	1	VBP
pickle	1	0.4	BP
pickle	0	0/1**	BP
	egress		
elevator	>0	0.4	VSP
master arm	OFF	1	BP
	time independent		
A-LOW	1	0.5	VSP
F-ACK	1	0.5	VSP

∗ This can be done in an overfly update to check the target's position. Second designate will activate FTT (Fixed Target Track).
∗∗ Releasing the pickle button is compulsory when the pickle button has been depressed.

The visual checks

Instrument
HUD
DED
MFD
caution panel

The conditions

Start probability: MP.
End probability: MP.

Name	**Start**	**End**
steerpoint type	TGT | IP	-
EWS mode	!OFF & !STBY	-
IFF	OFF	-
RWR	ON	-
master mode	A-G	!A-G
FCR	A-G	-
SMS	CCRP | LADD	-
sighting option	VRP | VIP	-
master arm	OFF	OFF
pickle	0	0
master lights	OFF	NORM
wheel brakes	OFF	OFF
landing gear	RAISED	RAISED
ATT/FPM switch	FPM	-

Additional rules

The following additional rules apply to this phase:

- The maximum airspeed for performing an A-G attack is 0.95 MACH.
- The altitude should always stay above the minimum release altitude of the chosen armament.

A.9 Guided attack

The actions

Name	**Value**	**Priority**	**Probability**
	ingress		
designate	1	0/1*	MP
slew	1	0	MP
designate	1	0/1*	MP
	engage		
master arm	MASTER ARM	1	VBP
laser arm	LASER ARM	0**	VBP
pickle	1	0.4	BP
pickle	0	0/1***	BP
	egress		
master arm	OFF	1	BP
laser arm	OFF	0**	VBP
	time independent		
A-LOW	1	0.5	VSP
F-ACK	1	0.5	VSP

∗ When bombing with LGB's locking the target is not necessary.
∗∗ When bombing with LGB's the laser should be used to fix the target. This is not compulsory because the wingman can also fix the target with his laser.
∗∗∗ Releasing the pickle button is compulsory when the pickle button has been depressed.

The visual checks

Instrument
HUD
DED
MFD
caution panel

The conditions

Start probability: BP.
End probability: MP.

Name	Start	End
master mode	A-G	!A-G
IFF	OFF	-
EWS mode	!OFF & !STBY	-
RWR	ON	-
SMS	Maverick | LGB	-
FCR	HSD | A-G radar	-
steerpoint type	TGT	-
master arm	OFF	OFF
pickle	0	0
master lights	OFF	NORM
landing gear	RAISED	RAISED
wheel brakes	OFF	OFF
ATT/FPM switch	FPM	-

Additional rules

The following additional rules apply to this phase:

- The maximum airspeed for performing an A-G attack is 0.95 MACH.
- The altitude should always stay above the minimum release altitude of the chosen armament.

A.10 HARM (High-speed Anti-Radiation Missile) attack

The actions

Name	Value	Priority	Probability
ingress			
designate	1	1	BP
slew	1	0	SP
engage			
master arm	MASTER ARM	1	VBP
pickle	1	0.4	BP
pickle	0	0/1*	BP
egress			
master arm	OFF	1	BP
time independent			
A-LOW	1	0.5	VSP
F-ACK	1	0.5	VSP

∗ Releasing the pickle button is compulsory when the pickle button has been depressed.

The visual checks

Instrument
HUD
DED
MFD
caution panel

The conditions

Start probability: BP.
End probability: MP.

Name	Start	End
master mode	A-G	!A-G
IFF	OFF	-
RWR	ON	-
EWS mode	!OFF & !STBY	-
SMS	HTS	-
master arm	OFF	OFF
steerpoint type	TGT	-
pickle	0	0
master lights	OFF	NORM
landing gear	RAISED	RAISED
wheel brakes	OFF	OFF
ATT/FPM switch	FPM	-

Additional rules

The following additional rules apply to this phase:

- The maximum airspeed for performing an A-G attack is 0.95 MACH.
- The altitude should always stay above the minimum release altitude of the chosen armament.

A.11 Taking evasive action

The actions

Name	Value	Priority	Probability
time independent			
ECM	ON	1/0*	MP
IFF	OFF	1	MP
chaff/flares	1	1	MP
master lights	OFF	0.7	SP

∗ The ECM pot might not be loaded.

The visual checks

Instrument
TWS

The conditions

Start probability: VBP.
End probability: BP.

Name	Start	End
RWR	ON	-
EWS mode	!OFF & !STBY	-
ML light	ON	OFF
master lights	-	OFF
landing gear	RAISED	RAISED
wheel brakes	OFF	OFF

A.12 Air refueling

The actions

Name	Value	Priority	Probability
approach			
INSTR mode	TCN	0.3	SP
TACAN function	AA-TR	0.3	SP
refueling			
air refuel door	OPEN	1	VBP
air refuel door	CLOSED	1	BP

The visual checks

Instrument
HUD
FCR
ECM
RDY light
AR/NWS light
DISC light
fuel

The conditions

Start probability: SP.
End probability: MP.

Name	Start	End
RDY light	OFF	OFF
air refuel door	CLOSED	CLOSED
master arm	OFF	-
landing gear	RAISED	RAISED
ECM	STBY	-
FCR	STBY	-
IFF	OFF	-

Additional rules

The following additional rules apply to this phase:

- If the RDY comes on the probability that air refueling has started is VBP.
- During air refueling the climbing rate should be around zero.
- The airspeed during air refueling is most likely between 290 and 350 KCAS.
- The AR DISC (disconnect) button is depressed during refueling the end probability is VBP.

A.13 Deep stall

The actions

Name	**Value**	**Priority**	**Probability**
recovering			
throttle	IDLE	1	MP
MPO	OVERRIDE	0/1*	BP
MPO	NORMAL	0/1*	BP

∗ Compulsory if the airplane is inverted.

The conditions

Start probability: SP.
End probability: VBP.

Name	**Start**	**End**
airspeed	-	>200
low speed warning	ON	OFF
aileron	0	-
elevator	0	-
MPO	NORMAL	NORMAL

Additional rules

The following additional rules apply to this phase:

- If the airplane is upright and the AOA is pegged at 30 degrees the probability that the airplane is in a deep stall is BP.
- If the airplane is inverted the AOA is pegged at -5 degrees the probability that the airplane is in a deep stall is BP.
- If the airplane is inverted the rudder will either be positive or negative during the deep stall.

A.14 Landing

The actions

Name	Value	Priority	Probability
approach			
jettison stores	1	0*	SP
landing gear	LOWERED	1	VBP
fuel flow	2300	0	VSP
speed brakes	>0	0	VSP
fuel flow	2000	0	VSP
touchdown			
throttle	IDLE	1	SP
wheel brakes	ON	1	BP
time independent			
F-ACK	1	0.5	VSP
hook	LOWERED	0**	VBP

∗ This is only done for emergency landings.
∗∗ This is used for landings on a carrier or for an emergency landing.

The visual checks

Instrument
HUD
DED
MFD
caution panel
speed brakes
U/C
wheel brakes

The conditions

Start probability: VSP.
End probability: VBP.

Name	Start	End
radio	7	7
speed brakes	0	>0
altitude	-	0
ground speed	-	>0 & <Max Taxi Speed
throttle	-	IDLE
pitch	-	0
climbing rate	-	0
landing gear	RAISED	LOWERED
roll	-	0
master arm	AUTO	AUTO
FCR	OFF	-
master mode	NAV	-

Additional rules

The following additional rules apply to this phase:

- If landing gear is lowered the airspeed should never exceed the maximum gear speed.
- If all starting constraints have been met and the internal landing detection system detects a landing the probability that the pilot is landing is BP.
- During the landing the pitch angle should not exceed 14 degrees.
- During a landing the absolute roll angle should be smaller than 70 degrees.
- If the pilot jettisons the stores he is making an emergency landing.
- If the pilot is making an emergency landing and the landing gear is lowered the pitch angle should be between 5 and 12 degrees.
- If the pilot is making an emergency landing and the landing gear is up the pitch angle should be between 3 and 9 degrees.
- If the pilot is making an emergency landing and the landing gear is lowered the airspeed should be between 120 and 190 degrees.
- If the pilot is making an emergency landing and the landing gear is up the airspeed should be between 100 and 150 degrees.
- If the FLIR (Forward Looking InfraRed) is turned on during landing then the FLIR must be turned off when normal visual cues appear, because flare might go wrong if FLIR is turned on.
- During the approach phase the altitude will be bigger than zero.
- During the touchdown phase the altitude will remain zero.

A.15 Aborting a landing

The actions

Name	**Value**	**Priority**	**Probability**
	aborting		
throttle	MIL	1	BP
throttle	MAX AB	0.2	VBP
speed brakes	0	1	SP
landing gear	RAISED	1	VBP
	time independent		
F-ACK	1	0.5	VSP

The visual checks

Instrument
HUD
DED
landing gear
speed brakes

The conditions

Start probability: VSP.
End probability: BP.

Name	Start	End
climbing rate	<0	>0
altitude	-	> min. altitude
landing gear	-	RAISED
speed brakes	>0	0
throttle	-	MIL | MAX AB
master arm	AUTO	-
FCR	OFF	-
master mode	NAV	-

Additional rules

The following additional rules apply to this phase:

- Aborting a landing can only be started if the system has detected previously that a landing has started.
- The altitude at the end of the situation should be higher than the altitude at the start of aborting the landing and should also be above the minimum altitude.

A.16 Flame-Out landing

The actions

Name	Value	Priority	Probability
	approach		
jettison stores	1	1	BP
EPU	ON	1	BP
landing gear	LOWERED	1	BP
	touchdown		
speed brakes	>0	1	VSP
wheel brakes	ON	1	BP
	time independent		
JFS*	START2	1	BP
F-ACK	1	0.5	VSP

∗ The JFS should be turned on under 20000 MSL (Mean Sea Level) to extend EPU operating time if some fuel is still available.

The visual checks

Instrument
HUD
DED
speed brakes
U/C
wheel brakes

The conditions

Start probability: VSP.
End probability: VBP.

Name	Start	End
speed brakes	0	1
ground speed	-	>0 & <Max Taxi Speed
throttle	-	IDLE
altitude	-	0
pitch	-	0
climbing rate	-	0
landing gear	RAISED	LOWERED
roll	-	0
master lights	-	NORM
master arm	AUTO	-
master mode	NAV	-
FCR	OFF	-

Additional rules

The following additional rules apply to this phase:

- For a flame out landing the engine must be shut down or the throttle set to IDLE (SFO: Simulated Flame Out) from the start.
- Airspeed should be consistently around the optimum glide speed.
- If altitude is smaller than 2000' MSL the JFS should be turned on.
- If landing gear is lowered the airspeed should never exceed the maximum gear speed.
- If all starting constraints have been met and the internal landing detection system detects a landing the start probability is BP.
- During the landing the pitch angle should not exceed 14 degrees.
- During a landing the absolute roll angle should be smaller than 70 degrees.
- If the landing gear is lowered the pitch angle should be between 5 and 12 degrees.
- If the landing gear is up the pitch angle should be between 3 and 9 degrees.
- If the FLIR (Forward Looking InfraRed) is turned on during landing then the FLIR must be turned off when normal visual cues appear, because flare might go wrong if FLIR is turned on.
- During the approach phase the altitude will be bigger than zero.
- During the touchdown phase the altitude will remain zero.

A.17 Taxiing from runway

The actions

Name	Value	Priority	Probability
taxiing			
NWS	ON	1	BP
throttle	IDLE	1	SP
wheel brakes	ON	1	MP
parking brakes	ON	1	MP
time independent			
master lights	OFF	0.8	SP
MFD	OFF	0.8	SP

The visual checks

Instrument
wheel brakes
master arm

The conditions

Start probability: VBP.
End probability: VBP.

Name	Start	End
NWS	-	ON
master lights	-	OFF
ground speed	>0 & <Max. Taxi Speed	0
altitude	0	0
climbing rate	0	0
landing gear	LOWERED	LOWERED
master arm	AUTO	AUTO
MFD	-	OFF
pitch	0	0
roll	0	0
speed brakes	-	>0
throttle	-	IDLE
wheel brakes	-	ON
parking brakes	-	ON

Additional rules

The following additional rules apply to this phase:

- Altitude, pitch and roll will remain zero while taxiing.

A.18 Shutting down

The actions

Name	Value	Priority	Probability
time independent			
A-LOW	1	0.5	VSP
F-ACK	1	0.5	VSP
FCR	NO RAD	1	SP
FCR	OFF	1	SP
ejection seat	DISARMED	1	MP
radio	0	1	SP

The visual checks

Instrument
DED
radio

The conditions

Start probability: BP.
End probability: BP.

Name	Start	End
master lights	OFF	OFF
radio	-	0
ground speed	0	0
altitude	0	0
climbing rate	0	0
landing gear	LOWERED	LOWERED
pitch	0	0
roll	0	0
throttle	IDLE	IDLE
parking brakes	ON	ON
FCR	-	OFF
RALT	-	OFF
air source	-	OFF
fuel pumps	-	OFF
master fuel	-	OFF
ejection seat	ARMED	DISARMED
INS	-	OFF
ECM	-	OFF
MFD	-	OFF
FCC	-	OFF
SMS	-	OFF
UFC	-	OFF
GPS	-	OFF
DL	-	OFF
HUD	-	OFF
EWS JMR	-	OFF
EWS CHAFF	-	OFF
EWS FLARE	-	OFF
EWS PWR	-	OFF

Appendix B

The knowledge base in XML format

B.1 The flight plan in XML

B.1.1 The schema

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns="flightplan"
  targetNamespace="flightplan"
  xml:lang="en">

<xsd:annotation>
  <xsd:documentation>
  This is a schema for a flightplan.
  </xsd:documentation>
</xsd:annotation>

<xsd:annotation>
  <xsd:documentation>
  The root tag containing all steerpoint tags.
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="flightplan">
  <xsd:sequence>
    <xsd:element ref="steerpoint" maxOccurs="unbounded" />
  </xsd:sequence>
</xsd:element>

<xsd:annotation>
  <xsd:documentation>
  The steerpoint tag contains information about the steerpoint,
  like heading to fly to the steerpoint, the altitude at which
  the pilot should fly over the steerpoint and the TOS (Time
  Over Steerpoint) which is the time at which the pilot should
```

```
  be over the steerpoint. It also contains two attributes, one
  that says what type of steerpoint it is and one that contains
  the number of the steerpoint.
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="steerpoint">
  <xsd:sequence>
    <xsd:element name="heading" type="xsd:integer"/>
    <xsd:element name="altitude" type="xsd:integer"/>
    <xsd:element name="TOS">
      <xsd:restriction base="time">
        <xsd:pattern value="hh:mm:ss"/>
      </xsd:restriction>
    </xsd:element>
    <xsd:element name="action" minOccurs="0" maxOccurs="unbounded" type="xsd:string"/>
  </xsd:sequence>
  <xsd:attribute name="type" type="steerpointType"/>
  <xsd:attribute name="number" type="xsd:integer"/>
</xsd:element>

<xsd:annotation>
  <xsd:documentation>
  A steerpoint can be one of the following types:
    - STPT: This is a normal steerpoint.
    - TGT: This is a steerpoint where a mission target
      is located.
    - IP: This steerpoint is the initial point for a
      pop-up attack.
  </xsd:documentation>
</xsd:annotation>
<xsd:simpleType name="steerpointType">
  <xsd:restriction base="xsd:string">
    <xsd:enumeration value="STPT"/>
    <xsd:enumeration value="TGT"/>
    <xsd:enumeration value="IP"/>
  </xsd:restriction>
</xsd:simpleType>

</xsd:schema>
```

B.1.2 An example flight plan in XML

```
<?xml version="1.0"?>

<!-- This is an example of a flight plan for an F16 fighter aircraft.
  This flight plan is NOT based on a real flight plan! -->


<flightplan xmlns="flightplan">
```

```
<!-- Departure airfield -->
<steerpoint type="STPT" number="1">
  <heading>120</heading>
  <altitude>100</altitude>
  <TOS>13:10:00</TOS>
  <action>Startup</action>
  <action>Taxiing to runway</action>
  <action>Taking off</action>
</steerpoint>
<!-- Navigational steerpoint -->
<steerpoint type="STPT" number="2">
  <heading>160</heading>
  <altitude>5000</altitude>
  <TOS>13:34:30</TOS>
</steerpoint>
<!-- Refueling steerpoint -->
<steerpoint type="STPT" number="3">
  <heading>180</heading>
  <altitude>10000</altitude>
  <TOS>14:05:00</TOS>
  <action>Air refueling</action>
</steerpoint>
<!-- Navigational steerpoint -->
<steerpoint type="STPT" number="4">
  <heading>260</heading>
  <altitude>5000</altitude>
  <TOS>14:28:00</TOS>
</steerpoint>
<!-- Initial point for a Visual attack -->
<steerpoint type="IP" number="5">
  <heading>270</heading>
  <altitude>1500</altitude>
  <TOS>14:35:00</TOS>
</steerpoint>
<!-- Target steerpoint for a visual attack -->
<steerpoint type="TGT" number="6">
  <heading>310</heading>
  <altitude>2500</altitude>
  <TOS>14:39:00</TOS>
  <action>Visual attack</action>
</steerpoint>
<!-- Navigational steerpoint -->
<steerpoint type="STPT" number="7">
  <heading>270</heading>
  <altitude>5000</altitude>
  <TOS>14:45:00</TOS>
</steerpoint>
<!-- Destination airfield -->
<steerpoint type="STPT" number="8">
```

```
    <heading>135</heading>
    <altitude>50</altitude>
    <TOS>15:00:00</TOS>
    <action>Landing</action>
    <action>Taxiing from runway</action>
    <action>Shutting down</action>
  </steerpoint>
</flightplan>
```

B.2 The XML schema for the knowledge base

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns="./KB"
  targetNamespace="./KB"
  xml:lang="en">

<xsd:annotation>
  <xsd:documentation>
  A schema for an XML file that describes a knowledge base for flying
  with an F16. The XML file will have to conform to the following
  hierarchy:
  - flight
    - situation
      - actions
        - phase
          - action
            .
            .
          .
          .
      - visual checks
        - instrument
          .
          .
      - constraints
        - constraint
          .
          .
    - situation
      .
      .
  </xsd:documentation>
</xsd:annotation>

<xsd:annotation>
  <xsd:documentation>
  The flight tag that contains an attribute with the name of the
  airplane that is described by the knowledge base and has situation
  tags as children.
```

```
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="flight">
  <xsd:sequence>
    <xsd:element ref="situation" maxOccurs="unbounded" />
  </xsd:sequence>
  <xsd:attribute name="airplane" type="xsd:string" use="required" />
</xsd:element>

<xsd:annotation>
  <xsd:documentation>
  The situation tag with an attribute that contains the name of the
  situation and child elements containing the list of time dependent
  and time independent actions, the list of visual checks and the
  list of constraints.
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="situation">
  <xsd:sequence>
    <xsd:element ref="constraints" minOccurs="0" maxOccurs="2"/>
    <xsd:element ref="actions" minOccurs="0" maxOccurs="2"/>
    <xsd:element ref="visual checks" minOccurs="0"/>
  </xsd:sequence>
  <xsd:attribute name="name" type="xsd:string" use="required" />
  <xsd:attribute name="timewindow" type="xsd:integer" use="required" />
</xsd:element>

<xsd:annotation>
  <xsd:documentation>
  The actions tag is the parent of a number of phase tags.
  The actions in the phases can be time dependent actions
  (which means that they have to be performed in the order
  in which they occur in the table) or time independent actions
  (they may be performed in any order). Time independent actions
  are grouped in a phase called "time independent".
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="actions">
  <xsd:sequence>
    <xsd:element ref="phase" maxOccurs="unbounded" />
  </xsd:sequence>
</xsd:element>

<xsd:annotation>
  <xsd:documentation>
  The phase tag is the parent of a number of action tags.
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="phase">
```

```
  <xsd:sequence>
    <xsd:element ref="action" maxOccurs="unbounded" />
  </xsd:sequence>
  <xsd:attribute name="name" type="xsd:string"/>
</xsd:element>

<xsd:annotation>
  <xsd:documentation>
  The action tag does not have any child tags, but does have three
  attributes. One containing the name of the control or instrument
  that action has an effect on. Another containing the priority
  value of the action. This value is a value between 0 and 1.
  And finally an attribute containing the fuzzy probability value
  of the action.
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="action" type="xsd:string">
  <xsd:attribute name="name" type="xsd:string" use="required" />
  <xsd:attribute name="priority" type="priorityValue" use="required" />
  <xsd:attribute name="probability" type="fuzzyValue" use="required" />
</xsd:element>

<xsd:annotation>
  <xsd:documentation>
  The PriorityValue type is a float between 0 and 1.
  </xsd:documentation>
</xsd:annotation>
<xsd:simpleType name="priorityValue">
  <xsd:restriction base="xsd:float">
    <xsd:minInclusive value="0"/>
    <xsd:maxInclusive value="1"/>
  </xsd:restriction>
</xsd:simpleType>

<xsd:annotation>
  <xsd:documentation>
  The FuzzyValue must be one of the following values:
  VBP, BP, MP, SP, VSP, VSN, SN, MN, BN, VBN.
  </xsd:documentation>
</xsd:annotation>
<xsd:simpleType name="fuzzyValue">
  <xsd:restriction base="xsd:string">
    <xsd:enumeration value="VBP"/>
    <xsd:enumeration value="BP"/>
    <xsd:enumeration value="MP"/>
    <xsd:enumeration value="SP"/>
    <xsd:enumeration value="VSP"/>
    <xsd:enumeration value="VSN"/>
    <xsd:enumeration value="SN"/>
```

```
    <xsd:enumeration value="MN"/>
    <xsd:enumeration value="BN"/>
    <xsd:enumeration value="VBN"/>
  </xsd:restriction>
</xsd:simpleType>

<xsd:annotation>
  <xsd:documentation>
  The visualChecks tag is the root tag for all instrument tags.
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="visualChecks">
  <xsd:sequence>
    <xsd:element ref="instrument" maxOccurs="unbounded" />
  </xsd:sequence>
</xsd:element>

<xsd:annotation>
  <xsd:documentation>
  The instrument tag is a tag describing an instrument that the
  pilot should check during a situation. For now it only has one
  attribute containing the name of the instrument.
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="instrument">
  <xsd:attribute name="name" type="xsd:string" use="required" />
</xsd:element>

<xsd:annotation>
  <xsd:documentation>
  The constraints tag is the parent tag for a set of constraint tags.
  It contains two attributes, the first contains the start
  probability, the second contains the end probability value.
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="constraints">
  <xsd:sequence>
    <xsd:element ref="constraint" maxOccurs="unbounded" />
  </xsd:sequence>
  <xsd:attribute name="endProbability" type="fuzzyValue" use="required"/>
  <xsd:attribute name="startProbability" type="fuzzyValue" use="required"/>
</xsd:element>

<xsd:annotation>
  <xsd:documentation>
  The constraint tag sets a condition on the value of a control or
  instrument for the start and/or the end of the situation. It
  contains one attribute with the name of the control or instrument
  and two optional attributes for the start and end value of the
```

```
  control or instrument.
  </xsd:documentation>
</xsd:annotation>
<xsd:element name="constraint" type="xsd:string">
  <xsd:attribute name="name" type="xsd:string" use="required" />
  <xsd:attribute name="start" type="xsd:string"/>
  <xsd:attribute name="end" type="xsd:string"/>
</xsd:element>

</xsd:schema>
```

B.3 The XML file of the knowledge base

```
<?xml version="1.0"?>

<!DOCTYPE variables SYSTEM "variables.dtd">

<flight aircraft="F16-C" xmlns="./KB">
  <situation name="Startup" timewindow="20">
    <actions>
      <phase name="startup">
        <action name="parking brakes" priority="1" probability="MP">&ON;</action>
        <action name="throttle" priority="0.8" probability="VSP">&MIL;</action>
        <action name="throttle" priority="1" probability="VSP">&IDLE;</action>
        <action name="JFS" priority="1" probability="BP">&START2;</action>
        <action name="throttle idle detent" priority="1" probability="BP">1</action>
        <action name="INS" priority="1" probability="BP">&ALIGN_NORM;</action>
      </phase>
      <phase name="time independent">
        <action name="air refuel door" priority="0 | 0.7" probability="SP">&OPEN;</action>
        <action name="air refuel door" priority="0 | 1" probability="SP">&CLOSED;</action>
        <action name="HUD" priority="0.9" probability="MP">&ON;</action>
        <action name="landing light" priority="0.8" probability="SP">&ON;</action>
        <action name="ejection seat" priority="0.8" probability="BP">&ARMED;</action>
        <action name="F-ACK" priority="0.5" probability="VSP">1</action>
        <action name="A-LOW" priority="0.5" probability="VSP">1</action>
      </phase>
    </actions>
    <visualChecks>
      <instrument name="HUD"/>
      <instrument name="speed brakes"/>
      <instrument name="wheel brakes"/>
      <instrument name="U/C"/>
      <instrument name="DED"/>
      <instrument name="MFD"/>
      <instrument name="fuel flow"/>
      <instrument name="HYD oil light"/>
      <instrument name="RDY light"/>
      <instrument name="DISC light"/>
```

```
    <instrument name="AR/NWS light"/>
  </visualChecks>
  <constraints startProbability="MP" endProbability="BP">
    <constraint name="landing gear" start="&LOWERED;" end="&LOWERED;"/>
    <constraint name="master mode" end="&NAV;"/>
    <constraint name="master arm" end="&AUTO;"/>
    <constraint name="master fuel" end="&ON;"/>
    <constraint name="fuel pumps" end="&NORM;"/>
    <constraint name="parking brakes" end="&ON;"/>
    <constraint name="radio" end="7"/>
    <constraint name="A/C lights" end="&ON;"/>
    <constraint name="landing lights" end="&ON;"/>
    <constraint name="master lights" end="&NORM;"/>
    <constraint name="FCR" end="&NO_RAD;"/>
    <constraint name="RALT" end="!&OFF;"/>
    <constraint name="TACAN function" end="&TR;"/>
    <constraint name="air source" end="&NORM;"/>
    <constraint name="ejection seat" start="&ARMED;" end="&DISARMED;"/>
    <constraint name="JFS" end="&OFF;"/>
    <constraint name="INS" end="&NAV;"/>
    <constraint name="ECM" end="&OFF;"/>
    <constraint name="MFD" end="!&OFF;"/>
    <constraint name="FCC" end="&ON;"/>
    <constraint name="SMS" end="&ON;"/>
    <constraint name="UFC" end="&ON;"/>
    <constraint name="GPS" end="&ON;"/>
    <constraint name="DL" end="&ON;"/>
    <constraint name="HUD" end="&ON;"/>
    <constraint name="EWS JMR" end="&ON;"/>
    <constraint name="EWS CHAFF" end="&ON;"/>
    <constraint name="EWS FLARE" end="&ON;"/>
    <constraint name="EWS PWR" end="&ON;"/>
    <constraint name="elevator trim" end="0"/>
    <constraint name="rudder trim" end="0"/>
    <constraint name="ground speed" start="0" end="0"/>
    <constraint name="altitude" start="0" end="0"/>
  </constraints>
</situation>


<situation name="Taxiing to runway" timewindow="10">
  <actions>
    <phase name="taxiing">
      <action name="parking brakes" priority="1" probability="MP">&OFF;</action>
      <action name="throttle" priority="1" probability="SP">>&IDLE;</action>
      <action name="throttle" priority="1" probability="SP">&IDLE;</action>
      <action name="wheel brakes" priority="1" probability="MP">&ON;</action>
    </phase>
    <phase name="time independent">
```

```
      <action name="wheel brakes" priority="0.6" probability="MP">&ON;</action>
      <action name="MPO" priority="1" probability="MP">&NORMAL;</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="speed brakes"/>
    <instrument name="caution panel"/>
    <instrument name="DED"/>
    <instrument name="fuel"/>
    <instrument name="fuel flow"/>
    <instrument name="wheel brakes"/>
    <instrument name="master arm"/>
  </visualChecks>
  <constraints startProbability="MP" endProbability="BP">
    <constraint name="parking brakes" start="&ON;" end="&OFF;"/>
    <constraint name="wheel brakes" start="&OFF;" end="&ON;"/>
    <constraint name="speed brakes" end=">0"/>
    <constraint name="NWS" start="&ON;" end="&ON;"/>
    <constraint name="landing gear" start="&LOWERED;" end="&LOWERED;"/>
    <constraint name="ground speed" start="0" end="0"/>
    <constraint name="throttle" start="&IDLE;" end="&IDLE;"/>
    <constraint name="altitude" start="0" end="0"/>
    <constraint name="pitch" start="0" end="0"/>
    <constraint name="roll" start="0" end="0"/>
    <constraint name="MPO" end="&NORMAL;"/>
    <constraint name="radio" start="7" end="7"/>
    <constraint name="master arm" start="&AUTO;" end="&AUTO;"/>
  </constraints>
</situation>


<situation name="Taking off" timewindow="5">
  <actions>
    <phase name="grounded">
      <action name="speed brakes" priority="0.8" probability="VSP">0</action>
      <action name="throttle" priority="1" probability="VSP">>&IDLE;</action>
      <action name="wheel brakes" priority="1" probability="SP">&OFF;</action>
      <action name="throttle" priority="0" probability="SP">&MAX_AB;</action>
    </phase>
    <phase name="airborne">
      <action name="elevator" priority="1" probability="VSP">>0</action>
      <action name="landing gear" priority="1" probability="VBP">&RAISED;</action>
      <action name="FCR" priority="0.7" probability="VSP">!&NO_RAD;</action>
    </phase>
    <phase name="time independent">
        <action name="F-ACK" priority="0.5" probability="VSP">1</action>
      </phase>
  </actions>
  <visualChecks>
```

```xml
    <instrument name="HUD"/>
    <instrument name="master arm"/>
    <instrument name="caution panel"/>
    <instrument name="radio"/>
    <instrument name="DED"/>
    <instrument name="speed brakes"/>
    <instrument name="U/C"/>
    <instrument name="AR/NWS light"/>
    <instrument name="MFD"/>
  </visualChecks>
  <constraints startProbability="SP" endProbability="VBP">
    <constraint name="speed brakes" start="1" end="0"/>
    <constraint name="ground speed" start="0" end=">0"/>
    <constraint name="NWS" end="&OFF;"/>
    <constraint name="throttle" start="&IDLE;" end=">&IDLE;"/>
    <constraint name="rudder" start="0" />
    <constraint name="rudder trim" start="0" />
    <constraint name="altitude" start="0" end=">&MIN_ALT;"/>
    <constraint name="pitch" start="0" />
    <constraint name="climbing rate" start="0" />
    <constraint name="radio" start="7" />
    <constraint name="FCR" start="&NO_RAD;" end="!&NO_RAD;"/>
  </constraints>
</situation>


<situation name="Aborting takeoff" timewindow="5">
  <actions>
    <phase name="aborting">
      <action name="throttle" priority="1" probability="BP">&IDLE;</action>
      <action name="speed brakes" priority="1" probability="BP">1</action>
      <action name="wheel brakes" priority="0" probability="BP">&ON;</action>
      <action name="hook" priority="0" probability="BP">&LOWERED;</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="HUD"/>
    <instrument name="DED"/>
    <instrument name="caution panel"/>
  </visualChecks>
  <constraints startProbability="VSP" endProbability="VBP">
    <constraint name="speed brakes" start="0" end="1"/>
    <constraint name="wheel brakes" start="&OFF;" end="&ON;"/>
    <constraint name="altitude" start="0" end="0"/>
    <constraint name="throttle" start=">&IDLE;" end="&IDLE;"/>
    <constraint name="ground speed" start=">0" end="0"/>
  </constraints>
</situation>
```

```xml
<situation name="Normal flight" timewindow="60">
  <visualChecks>
    <instrument name="HUD"/>
    <instrument name="MFD"/>
  </visualChecks>
  <constraints startProbability="VBP" endProbability="VSP">
    <constraint name="master mode" start="&NAV;"/>
    <constraint name="master arm" start="&OFF;"/>
    <constraint name="master lights" start="&ON;"/>
    <constraint name="landing gear" start="&RAISED;" end="&RAISED;"/>
    <constraint name="wheel brakes" start="&OFF;" end="&OFF;"/>
  </constraints>
</situation>


<situation name="Dogfight" timewindow="30">
  <actions>
    <phase name="ingress">
      <action name="FCR" priority="0 | 1" probability="VSP">&ACM;</action>
      <action name="SMS" priority="1" probability="MP">&AAM;</action>
      <action name="ECM" priority="0.9" probability="VSP">&ON;</action>
    </phase>
    <phase name="engage">
      <action name="master arm" priority="1" probability="BP">&MASTER_ARM;</action>
      <action name="pickle" priority="0.4" probability="BP">1</action>
      <action name="pickle" priority="0 | 1" probability="BP">0</action>
    </phase>
    <phase name="egress">
      <action name="master arm" priority="1" probability="VSP">&AUTO;</action>
      <action name="master mode" priority="0.7" probability="VSP">&NAV;</action>
      <action name="FCR" priority="0" probability="VSP">&SLW; | &RWS;</action>
      <action name="master lights" priority="0.6" probability="SP">&NORM;</action>
    </phase>
    <phase name="time independent">
      <action name="chaff/flares" priority="0.4" probability="MP">1</action>
      <action name="throttle" priority="0" probability="SP">&MAX_AB;</action>
      <action name="F-ACK" priority="0.5" probability="VSP">1</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="HUD"/>
    <instrument name="radio"/>
    <instrument name="caution panel"/>
    <instrument name="MFD"/>
    <instrument name="DED"/>
  </visualChecks>
  <constraints startProbability="SP" endProbability="BP">
    <constraint name="IFF" start="&OFF;" />
```

```
    <constraint name="RWR" start="&ON;" />
    <constraint name="EWS mode" start="!&OFF; &amp; !&STBY;" />
    <constraint name="master mode" start="&A-A; | &DGFT; | &MSL_OVRD;" end="&NAV;"/>
    <constraint name="master arm" start="&OFF;" end="&AUTO;"/>
    <constraint name="master lights" start="&OFF;" end="&NORM;"/>
    <constraint name="FCR" start="&ACM;" />
    <constraint name="landing gear" start="&RAISED;" end="&RAISED;"/>
    <constraint name="wheel brakes" start="&OFF;" end="&OFF;"/>
    <constraint name="ATT/FPM switch" start="&FPM;" />
  </constraints>
</situation>


<situation name="Visual attack" timewindow="30">
  <actions>
    <phase name="ingress">
      <action name="designate" priority="0.3" probability="MP">1</action>
      <action name="slew" priority="0" probability="MP">1</action>
    </phase>
    <phase name="engage">
      <action name="master arm" priority="1" probability="VBP">&MASTER_ARM;</action>
      <action name="elevator" priority="0.4" probability="VSP">&lt;0</action>
      <action name="pickle / fire gun" priority="0.4" probability="BP">1</action>
      <action name="pickle / fire gun" priority="0 | 1" probability="BP">0</action>
    </phase>
    <phase name="egress">
      <action name="elevator" priority="0.4" probability="VSP">>0</action>
      <action name="master arm" priority="1" probability="BP">&OFF;</action>
    </phase>
    <phase name="time independent">
      <action name="A-LOW" priority="0.5" probability="VSP">1</action>
      <action name="F-ACK" priority="0.5" probability="VSP">1</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="HUD"/>
    <instrument name="DED"/>
    <instrument name="MFD"/>
    <instrument name="caution panel"/>
  </visualChecks>
  <constraints startProbability="MP" endProbability="MP">
    <constraint name="master mode" start="&A-G;" end="!&A-G;"/>
    <constraint name="master arm" start="&OFF;" end="&OFF;"/>
    <constraint name="steerpoint type" start="&TGT; | &IP;" />
    <constraint name="EWS mode" start="!&OFF; &amp; !&STBY;" />
    <constraint name="IFF" start="&OFF;" />
    <constraint name="RWR" start="&ON;" />
    <constraint name="SMS" start="&A-G_GUN; | &RCKT; | &CCIP; | &DTOS; | &TARS;" />
    <constraint name="FCR" start="&A-G;" />
```

```
      <constraint name="pickle" start="0" end="0"/>
      <constraint name="master lights" start="&OFF;" end="&NORM;"/>
      <constraint name="landing gear" start="&RAISED;" end="&RAISED;"/>
      <constraint name="wheel brakes" start="&OFF;" end="&OFF;"/>
      <constraint name="ATT/FPM switch" start="&FPM;" />
    </constraints>
  </situation>


  <situation name="Nonvisual attack" timewindow="30">
    <actions>
      <phase name="ingress">
        <action name="designate" priority="0.3" probability="MP">1</action>
        <action name="designate" priority="0" probability="MP">1</action>
        <action name="slew" priority="0" probability="MP">1</action>
      </phase>
      <phase name="engage">
        <action name="master arm" priority="1" probability="VBP">&MASTER_ARM;</action>
        <action name="pickle" priority="0.4" probability="BP">1</action>
        <action name="pickle" priority="0 | 1" probability="BP">0</action>
      </phase>
      <phase name="egress">
        <action name="elevator" priority="0.4" probability="VSP">>0</action>
        <action name="master arm" priority="1" probability="BP">OFF</action>
      </phase>
      <phase name="time independent">
        <action name="A-LOW" priority="0.5" probability="VSP">1</action>
        <action name="F-ACK" priority="0.5" probability="VSP">1</action>
      </phase>
    </actions>
    <visualChecks>
      <instrument name="HUD"/>
      <instrument name="DED"/>
      <instrument name="MFD"/>
      <instrument name="caution panel"/>
    </visualChecks>
    <constraints startProbability="MP" endProbability="MP">
      <constraint name="steerpoint type" start="&TGT; | &IP;" />
      <constraint name="EWS mode" start="!&OFF; &amp; !&STBY;" />
      <constraint name="IFF" start="&OFF;" />
      <constraint name="RWR" start="&ON;" />
      <constraint name="master mode" start="&A-G;" end="!&A-G;"/>
      <constraint name="FCR" start="&A-G;" />
      <constraint name="SMS" start="&CCRP; | &LADD;" />
      <constraint name="sighting option" start="&VRP; | &VIP;" />
      <constraint name="master arm" start="&OFF;" end="&OFF;"/>
      <constraint name="pickle" start="0" end="0"/>
      <constraint name="master lights" start="&OFF;" end="&NORM;"/>
      <constraint name="wheel brakes" start="&OFF;" end="&OFF;"/>
```

```
    <constraint name="landing gear" start="&RAISED;" end="&RAISED;"/>
    <constraint name="ATT/FPM switch" start="&FPM;" />
  </constraints>
</situation>


<situation name="Guided attack" timewindow="30">
  <actions>
    <phase name="ingress">
      <action name="designate" priority="0 | 1" probability="MP">1</action>
      <action name="slew" priority="0" probability="MP">1</action>
      <action name="designate" priority="0 | 1" probability="MP">1</action>
    </phase>
    <phase name="engage">
      <action name="master arm" priority="1" probability="VBP">&MASTER_ARM;</action>
      <action name="laser arm" priority="0" probability="VBP">&LASER_ARM;</action>
      <action name="pickle" priority="0.4" probability="BP">1</action>
      <action name="pickle" priority="0 | 1" probability="BP">0</action>
    </phase>
    <phase name="egress">
      <action name="master arm" priority="1" probability="BP">&OFF;</action>
      <action name="laser arm" priority="0" probability="VBP">&OFF;</action>
    </phase>
    <phase name="time independent">
      <action name="A-LOW" priority="0.5" probability="VSP">1</action>
      <action name="F-ACK" priority="0.5" probability="VSP">1</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="HUD"/>
    <instrument name="DED"/>
    <instrument name="MFD"/>
    <instrument name="caution panel"/>
  </visualChecks>
  <constraints startProbability="BP" endProbability="MP">
    <constraint name="master mode" start="&A-G;" end="!&A-G;"/>
    <constraint name="EWS mode" start="!&OFF; &amp; !&STBY;" />
    <constraint name="RWR" start="&ON;" />
    <constraint name="IFF" start="&OFF;" />
    <constraint name="SMS" start="&MAVERICK; | &LGB;" />
    <constraint name="FCR" start="&HSD; | &A-G_RADAR;" />
    <constraint name="steerpoint type" start="&TGT;" />
    <constraint name="master arm" start="&OFF;" end="&OFF;"/>
    <constraint name="pickle" start="0" end="0"/>
    <constraint name="master lights" start="&OFF;" end="&NORM;"/>
    <constraint name="landing gear" start="&RAISED;" end="&RAISED;"/>
    <constraint name="wheel brakes" start="&OFF;" end="&OFF;"/>
    <constraint name="ATT/FPM switch" start="&FPM;" />
  </constraints>
```

```
</situation>


<situation name="HARM attack" timewindow="30">
  <actions>
    <phase name="ingress">
      <action name="designate" priority="1" probability="BP">1</action>
      <action name="slew" priority="0" probability="SP">1</action>
    </phase>
    <phase name="engage">
      <action name="master arm" priority="1" probability="VBP">&MASTER_ARM;</action>
      <action name="pickle" priority="0.4" probability="BP">1</action>
      <action name="pickle" priority="0 | 1" probability="BP">0</action>
    </phase>
    <phase name="egress">
      <action name="master arm" priority="1" probability="BP">&OFF;</action>
    </phase>
    <phase name="time independent">
      <action name="A-LOW" priority="0.5" probability="VSP">1</action>
      <action name="F-ACK" priority="0.5" probability="VSP">1</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="HUD"/>
    <instrument name="DED"/>
    <instrument name="MFD"/>
    <instrument name="caution panel"/>
  </visualChecks>
  <constraints startProbability="BP" endProbability="MP">
    <constraint name="master mode" start="&A-G;" end="!&A-G;"/>
    <constraint name="RWR" start="&ON;" />
    <constraint name="IFF" start="&OFF;" />
    <constraint name="EWS mode" start="!&OFF; &amp; !&STBY;" />
    <constraint name="SMS" start="&HTS;" />
    <constraint name="master arm" start="&OFF;" end="&OFF;"/>
    <constraint name="steerpoint type" start="&TGT;" />
    <constraint name="pickle" start="0" end="0"/>
    <constraint name="master lights" start="&OFF;" end="&NORM;"/>
    <constraint name="landing gear" start="&RAISED;" end="&RAISED;"/>
    <constraint name="wheel brakes" start="&OFF;" end="&OFF;"/>
    <constraint name="ATT/FPM switch" start="&FPM;" />
  </constraints>
</situation>


<situation name="Taking evasive action" timewindow="5">
  <actions>
    <phase name="time independent">
      <action name="ECM" priority="0 | 1" probability="MP">&ON;</action>
```

```
      <action name="IFF" priority="1" probability="MP">&OFF;</action>
      <action name="chaff/flares" priority="1" probability="MP">1</action>
      <action name="master lights" priority="0.7" probability="SP">&OFF;</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="TWS"/>
  </visualChecks>
  <constraints startProbability="VBP" endProbability="BP">
    <constraint name="RWR" start="&ON;" />
    <constraint name="EWS mode" start="!&OFF; &amp; !&STBY;" />
    <constraint name="ML light" start="&ON;" end="&OFF;"/>
    <constraint name="master lights" end="&OFF;"/>
    <constraint name="landing gear" start="&RAISED;" end="&RAISED;"/>
    <constraint name="wheel brakes" start="&OFF;" end="&OFF;"/>
  </constraints>
</situation>


<situation name="Air refueling" timewindow="10">
  <actions>
    <phase name="approach">
      <action name="INSTR mode" priority="0.3" probability="SP">&TCN;</action>
      <action name="TACAN function" priority="0.3" probability="SP">&AA-TR;</action>
    </phase>
    <phase name="refueling">
      <action name="air refuel door" priority="1" probability="VBP">&OPEN;</action>
      <action name="air refuel door" priority="1" probability="BP">&CLOSED;</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="HUD"/>
    <instrument name="FCR"/>
    <instrument name="ECM"/>
    <instrument name="RDY light"/>
    <instrument name="AR/NWS light"/>
    <instrument name="DISC light"/>
    <instrument name="fuel"/>
  </visualChecks>
  <constraints startProbability="SP" endProbability="MP">
    <constraint name="RDY light" start="&OFF;" end="&OFF;"/>
    <constraint name="air refuel door" start="&CLOSED;" end="&CLOSED;"/>
    <constraint name="master arm" start="&OFF;" />
    <constraint name="landing gear" start="&RAISED;" end="&RAISED;"/>
    <constraint name="ECM" start="&STBY;" />
    <constraint name="FCR" start="&STBY;" />
    <constraint name="IFF" start="&OFF;" />
  </constraints>
</situation>
```

```
<situation name="Deep stall" timewindow="3">
  <actions>
    <phase name="recovering">
      <action name="throttle" priority="1" probability="MP">&IDLE;</action>
      <action name="MPO" priority="0 | 1" probability="BP">&OVERRIDE;</action>
      <action name="MPO" priority="0 | 1" probability="BP">&NORMAL;</action>
    </phase>
  </actions>
  <constraints startProbability="SP" endProbability="VBP">
    <constraint name="airspeed" end=">200"/>
    <constraint name="low speed warning" start="&ON;" end="&OFF;"/>
    <constraint name="aileron" start="0" />
    <constraint name="elevator" start="0" />
    <constraint name="MPO" start="&NORMAL;" end="&NORMAL;"/>
  </constraints>
</situation>


<situation name="Landing" timewindow="30">
  <actions>
    <phase name="approach">
      <action name="jettison stores" priority="0" probability="SP">1</action>
      <action name="landing gear" priority="1" probability="VBP">&LOWERED;</action>
      <action name="fuel flow" priority="0" probability="VSP">2300</action>
      <action name="speed brakes" priority="0" probability="VSP">>0</action>
      <action name="fuel flow" priority="0" probability="VSP">2000</action>
    </phase>
    <phase name="touchdown">
      <action name="throttle" priority="1" probability="SP">&IDLE;</action>
      <action name="wheel brakes" priority="1" probability="BP">&ON;</action>
    </phase>
    <phase name="time independent">
      <action name="F-ACK" priority="0.5" probability="VSP">1</action>
      <action name="hook" priority="0" probability="VBP">&LOWERED;</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="HUD"/>
    <instrument name="DED"/>
    <instrument name="MFD"/>
    <instrument name="caution panel"/>
    <instrument name="speed brakes"/>
    <instrument name="U/C"/>
    <instrument name="wheel brakes"/>
  </visualChecks>
  <constraints startProbability="VSP" endProbability="VBP">
    <constraint name="radio" start="7" end="7"/>
```

```
    <constraint name="speed brakes" start="0" end=">0"/>
    <constraint name="altitude" end="0"/>
    <constraint name="ground speed" end=">0 &amp; &lt;&MAX_TAXI_SPEED;"/>
    <constraint name="throttle" end="&IDLE;"/>
    <constraint name="pitch" end="0"/>
    <constraint name="climbing rate" end="0"/>
    <constraint name="landing gear" start="&RAISED;" end="&LOWERED;"/>
    <constraint name="roll" end="0"/>
    <constraint name="master arm" start="&AUTO;" end="&AUTO;"/>
    <constraint name="FCR" start="&OFF;" />
    <constraint name="master mode" start="&NAV;" />
  </constraints>
</situation>


<situation name="Aborting a landing" timewindow="5">
  <actions>
    <phase name="aborting">
      <action name="throttle" priority="1" probability="BP">&MIL;</action>
      <action name="throttle" priority="0.2" probability="VBP">&MAX_AB;</action>
      <action name="speed brakes" priority="1" probability="SP">0</action>
      <action name="landing gear" priority="1" probability="VBP">&RAISED;</action>
    </phase>
    <phase name="time independent">
      <action name="F-ACK" priority="0.5" probability="VSP">1</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="HUD"/>
    <instrument name="DED"/>
    <instrument name="landing gear"/>
    <instrument name="speed brakes"/>
  </visualChecks>
  <constraints startProbability="VSP" endProbability="BP">
    <constraint name="climbing rate" start="&lt;0" end=">0"/>
    <constraint name="altitude" end=">&MIN_ALT;"/>
    <constraint name="landing gear" end="&RAISED;"/>
    <constraint name="speed brakes" start=">0" end="0"/>
    <constraint name="throttle" end="&MIL; | &MAX_AB;"/>
    <constraint name="master arm" start="&AUTO;" />
    <constraint name="FCR" start="&OFF;" />
    <constraint name="master mode" start="&NAV;" />
  </constraints>
</situation>


<situation name="Flame out landing" timewindow="30">
  <actions>
    <phase name="approach">
```

```
        <action name="jettison stores" priority="1" probability="BP">1</action>
        <action name="EPU" priority="1" probability="BP">&ON;</action>
        <action name="landing gear" priority="1" probability="BP">&LOWERED;</action>
      </phase>
      <phase name="touchdown">
        <action name="speed brakes" priority="1" probability="VSP">>0</action>
        <action name="wheel brakes" priority="1" probability="BP">ON</action>
      </phase>
      <phase name="time independent">
        <action name="JFS" priority="1" probability="BP">&START2;</action>
        <action name="FCR" priority="0.4" probability="SP">&OFF;</action>
        <action name="F-ACK" priority="0.5" probability="VSP">1</action>
      </phase>
    </actions>
    <visualChecks>
      <instrument name="HUD"/>
      <instrument name="DED"/>
      <instrument name="speed brakes"/>
      <instrument name="U/C"/>
      <instrument name="wheel brakes"/>
    </visualChecks>
    <constraints startProbability="VSP" endProbability="VBP">
      <constraint name="speed brakes" start="0" end="1"/>
      <constraint name="ground speed" end=">0 &amp; &lt;&MAX_TAXI_SPEED;"/>
      <constraint name="throttle" end="&IDLE;"/>
      <constraint name="altitude" end="0"/>
      <constraint name="pitch" end="0"/>
      <constraint name="climbing rate" end="0"/>
      <constraint name="landing gear" start="&RAISED;" end="&LOWERED;"/>
      <constraint name="roll" end="0"/>
      <constraint name="master lights" end="&NORM;"/>
      <constraint name="master arm" start="&AUTO;" />
      <constraint name="master mode" start="&NAV;" />
      <constraint name="FCR" start="&OFF;" />
    </constraints>
  </situation>


  <situation name="Taxiing from runway" timewindow="10">
    <actions>
      <phase name="taxiing">
        <action name="NWS" priority="1" probability="BP">&ON;</action>
        <action name="throttle" priority="1" probability="SP">&IDLE;</action>
        <action name="wheel brakes" priority="1" probability="MP">&ON;</action>
        <action name="parking brakes" priority="1" probability="MP">&ON;</action>
      </phase>
      <phase name="time independent">
        <action name="master lights" priority="0.8" probability="SP">&OFF;</action>
        <action name="MFD" priority="0.8" probability="SP">&OFF;</action>
```

```
    </phase>
  </actions>
  <visualChecks>
    <instrument name="wheel brakes"/>
    <instrument name="master arm"/>
  </visualChecks>
  <constraints startProbability="VBP" endProbability="VBP">
    <constraint name="NWS" end="&ON;"/>
    <constraint name="master lights" end="&OFF;"/>
    <constraint name="ground speed" start=">0 &amp; &lt;&MAX_TAXI_SPEED;" end="0"/>
    <constraint name="altitude" start="0" end="0"/>
    <constraint name="climbing rate" start="0" end="0"/>
    <constraint name="landing gear" start="&LOWERED;" end="&LOWERED;"/>
    <constraint name="master arm" start="&AUTO;" end="&AUTO;"/>
    <constraint name="MFD" end="&OFF;"/>
    <constraint name="pitch" start="0" end="0"/>
    <constraint name="roll" start="0" end="0"/>
    <constraint name="speed brakes" end=">0"/>
    <constraint name="throttle" end="&IDLE;"/>
    <constraint name="wheel brakes" end="&ON;"/>
    <constraint name="parking brakes" end="&ON;"/>
  </constraints>
</situation>


<situation name="Shutting down" timewindow="15">
  <actions>
    <phase name="time independent">
      <action name="A-LOW" priority="0.5" probability="VSP">1</action>
      <action name="F-ACK" priority="0.5" probability="VSP">1</action>
      <action name="FCR" priority="1" probability="SP">&NO_RAD;</action>
      <action name="FCR" priority="1" probability="SP">&OFF;</action>
      <action name="ejection seat" priority="1" probability="MP">&DISARMED;</action>
      <action name="radio" priority="1" probability="SP">0</action>
    </phase>
  </actions>
  <visualChecks>
    <instrument name="DED"/>
    <instrument name="radio"/>
  </visualChecks>
  <constraints startProbability="BP" endProbability="BP">
    <constraint name="master lights" start="&OFF;" end="&OFF;"/>
    <constraint name="radio" end="0"/>
    <constraint name="ground speed" start="0" end="0"/>
    <constraint name="altitude" start="0" end="0"/>
    <constraint name="climbing rate" start="0" end="0"/>
    <constraint name="landing gear" start="&LOWERED;" end="&LOWERED;"/>
    <constraint name="pitch" start="0" end="0"/>
    <constraint name="roll" start="0" end="0"/>
```

```
      <constraint name="throttle" start="&IDLE;" end="&IDLE;"/>
      <constraint name="parking brakes" start="&ON;" end="&ON;"/>
      <constraint name="FCR" end="&OFF;"/>
      <constraint name="RALT" end="&OFF;"/>
      <constraint name="air source" end="&OFF;"/>
      <constraint name="fuel pumps" end="&OFF;"/>
      <constraint name="master fuel" end="&OFF;"/>
      <constraint name="ejection seat" start="&ARMED;" end="&DISARMED;"/>
      <constraint name="INS" end="&OFF;"/>
      <constraint name="ECM" end="&OFF;"/>
      <constraint name="MFD" end="&OFF;"/>
      <constraint name="FCC" end="&OFF;"/>
      <constraint name="SMS" end="&OFF;"/>
      <constraint name="UFC" end="&OFF;"/>
      <constraint name="GPS" end="&OFF;"/>
      <constraint name="DL" end="&OFF;"/>
      <constraint name="HUD" end="&OFF;"/>
      <constraint name="EWS JMR" end="&OFF;"/>
      <constraint name="EWS CHAFF" end="&OFF;"/>
      <constraint name="EWS FLARE" end="&OFF;"/>
      <constraint name="EWS PWR" end="&OFF;"/>
    </constraints>
  </situation>

</flight>
```

Appendix C

The controls and instruments

In this chapter all controls and instruments that are referred to in the knowledge base are described. Also for controls or instruments that can only have a limited amount of values those values are given. For every control or instrument first the position in the cockpit is given according to the layout in figure C.1. Then the name, the possible values and the function of that control or instrument is described. The values are usually given as a description of the state of the control or instrument in capital letters, with the exception of some controls that can have the value 1 or the values 0 and 1. Controls that have only one value are usually buttons the pilot can push. Controls with the values 0 and 1 are the buttons with which the pilot can fire a gun and the pickle button. These buttons have an effect as long as the pilot keeps them depressed. That's why for those buttons the moment it is depressed (1) as well as the moment it is released (0) are important.

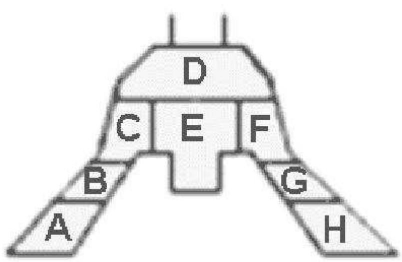

Figure C.1: The cockpit layout.

The locations of the controls or instruments are either the locations of the switches for those controls or instruments or the locations of the meters that display the value for that control or instrument. For example the power switch for the UFC panel is located at panel G, while the UFC panel itself is located on panel D. In these cases the location that is specified in front of the name of the control or instrument is the location of the switch while the location of the display of the control or instrument might be given in the description of the control or instrument. In the other cases the location is the location of the meter that displays the value or a "-" if the location of the switch or control is unknows or if there is no display or switch for the control or instrument on the layout in figure C.1. The following controls and instruments are referred to in the knowledge base:

(D) A-LOW: *1.* This is a button on the ICP with which the pilot can display the page with the minimum altitude on the DED.

(B) A/C lights (Anti Collision lights): *ON, OFF.*

(B) Air refuel door: *OPEN, CLOSED.* This door should be opened when the pilot is refueling in the air.

(G) Air source: *OFF, NORM, DUMP, RAM.* This controls the pressurization of the cockpit and the fuel tanks.

(HUD) Airspeed (in KIAS). This is the indicated airspeed in knots in the HUD.

(E) Altitude (in AGL). This is the altitude from the ground. This can only be measured if the radar altimeter is switched on.

(-) AR (Air Refuel) disconnect button: *1.* This button can be pushed by the pilot to disconnect the refuel boom when there are problems during refueling.

(-) AR/NWS (Nose Wheel Steering/ Air refueling) light. This light is on when NWS is engaged or when the air refuel door is open. This light is located on a small vertical panel to the right of the HUD.

(F) ATT/FPM switch *OFF, FPM.* This switch can be used to switch on the FPM.

(F) Caution panel. This panel displays all the defects or problems of the airplane.

(C) Chaff/Flares *1.* This is an indication that the pilot has activated a release program for chaff or flares. The pilot can preprogram a release program to release a series of chaff and flares simultaneously.

(E) Climbing rate.

(D) DED (Data Entry Display). This display is located next to the ICP and displays information about steerpoints and minimum altitude among other things.

(-) Designate: *1.* The pilot can push this button to lock the radar to a target.

(-) DISC light. This light goes on when the tanker has disconnected the boom during air refueling. This is located on the same panel as the AR/NWS light to the right of the HUD.

(G) DL (Data Link): *OFF, ON.* The data link can be switched on if some data should be downloaded to the F16. This can be done for example by an AWACS.

(B) ECM (Electronic Counter Measures): *OFF, STBY, ON.* The ECM pod can be used to jam enemy radars and radar guided missiles.

(C) Ejection seat: *ARMED, DISARMED.* If the ejection seat is disarmed ejecting is impossible.

(-) Elevator.

(A) Elevator trim.

(B) EPU (Emergency Power Unit): *ON, OFF.* The EPU should be switched on when the engines quit because some instruments will not receive any power when the engines fail.

(C) EWS (Electronic Warfare System). This is a group of controls and instruments that can be used to divert an attack.

- **(C) EWS JMR:** *OFF, ON.* This switch should be set to ON to use the ECM jammer automatically.

- **(C) EWS CHAFF:** *OFF, ON*. This switch should be set to on for the EWS to release chaff automatically.
- **(C) EWS FLARE:** *OFF, ON*. Flares can be released automatically by the EWS only when this switch is set to ON.
- **(C) EWS PWR:** *OFF, ON*.
- **(C) EWS mode:** *OFF, MAN, STBY, AUTO, SEMI*. These are different levels of atomisation of the EWS. In SEMI or AUTO mode the EWS will release chaff and/or flares automatically.

(C) F-ACK: *1*. This is a button with which the pilot can turn the PFD (Pilot Fault Display) on and off and can cycle through the detected faults. The faults can also be displayed on the DED when the DED data switch is set to PFL (Pilot Fault List) data.

(G) FCC (Fire Control Computer): *ON, OFF*. The fire control computer calculates missile paths and help the pilot to execute attacks more accurately.

(F) FCR (Fire Control Radar):. The FCR is further described in the next section about the MFD's.

(-) Fire gun: *0, 1*. With this button the pilot can fire the A-G or A-A gun.

(D) FLIR (Forward Looking InfraRed): *ON, OFF*. The FLIR system enables the pilot to get an infrared picture of the surroundings.

(D) Fuel flow. This is the fuel flow that goes to the engine.

(B) Fuel pumps: *OFF, NORM, AFT, FWD*. With this switch the pumps that are used to pump fuel to the engine can be turned on or off.

(G) GPS: *ON, OFF*.

(-) Ground speed.

(-) Hook: *RAISED, LOWERED*. The hook can be lowered when the pilot is landing on a carrier ship or when making an emergency landing.

(D) HUD (Head Up Display): *ON, OFF*.

(D) ICP (Instrument Control Panel). This panel is located below the HUD and contains buttons with which the pilot can for example select steerpoints or display the F-ACK page on the DED.

(D) IFF (Identify Friend or Foe): *ON, OFF*. If this system is switched on it broadcasts a signal from which other aircrafts can identify whether they are dealing with a friend or a foe. This system will be switched off when the aircraft enters enemy territory.

(G) INS (Inertial Navigation System): *ALIGN NORM, NAV, OFF*. This system computes the aircraft's position in latitude and longitude using the acceleration and deceleration of the airplane. The status of the INS can be checked in the DED.

(E) INSTR (Instrument) mode: *TCN, TCN-ILS, NAV, NAV-ILS*. This switch can be used to enable the TACAN and the ILS.

(C) Jettison stores: *1.* The jettison stores button can be pushed to jettison all stores when an emergency occurs.

(B) JFS (Jet Fuel Starter): *OFF, START1, START2.* This switch should be switched to START2 to start the engine.

(C) Landing gear: *RAISED, LOWERED.*

(C) Landing lights: *ON, OFF.*

(C) Laser arm: *LASER ARM, OFF.* The laser arm should be set to LASER ARM when executing an attack with laser guided bombs.

(-) Low speed warning: *ON, OFF.* The low speed warning horn will sound when a stall is imminent.

(C) Master arm: *OFF, MASTER ARM, SIM.* The weapons can only be fired when this switch is set to MASTER ARM.

(B) Master fuel: *ON, OFF.*

(B) Master lights: *NORM, OFF.*

(-) Master mode: *NAV, A-A, A-G, S-J, E-J, MSL OVRD, DGFT.* These are the possible modes for the FCC. NAV is the default mode and is selected automatically when no other mode is selected. A-A and A-G are combat modes that can be selected with buttons on the ICP. S-J (Stores Jettison) can be selected from the SMS page of the MFD and E-J (Emergency Jettison) is selected when the emergency jettison button is used. For DGFT (Dogfight) and MSL OVRD (Missile Override) there is a special switch on the stick with three states: OFF, DGFT and MSL OVRD. MSL OVRD is used for Medium Range Missiles like the AIM-120 and AIM-7. DGFT mode is used for Short Range missiles like the AIM-9 and it brings up the AIM-9 view as well as the EEGS view on the HUD.

(-) ML (Missile Launch) light: *ON, OFF.* This light will go on when the RWR detects a radar guided missile has been launched.

(B) MPO (Manual Pitch Override): *NORMAL, OVERRIDE.* This switched can be used to override the flight computer when recovering from a deep stall. Normally the flight computer locks all controls when the airplane is in a deep stall and shuts the pilot out of the control loop.

(D) NWS (Nose Wheel Steering): *ON, OFF.* Nose wheel steering can be switched on for taxiing.

(C) Parking brakes: *O*N, OFF, ANTI-SKID.

(-) Pickle: *0*, 1. The pickle button can be depressed to give the FCR permission to release the bombs.

(-) Pitch.

(F) RALT (Radar Altimeter): *OFF, STBY, ON.* The radar altimeter calculates the altitude from the ground.

(B) Radio: *0-7*. The radio can be set to different channels. These radio modes 0 to 7 have the following meanings: Off, to the entire flight, to a package, to and from a package, in the proximity (40 nm), guard, broadcast, to the tower set in the TACAN channel.

(-) RDY light: *ON, OFF*. The ready light goes on during air refueling when a tanker gives a clearance for contact. It is located on the vertical panel to the right of the HUD.

(-) Roll.

(-) Rudder.

(A) Rudder trim.

(D) RWR (Radar Warning Receiver): *ON, OFF*. If the RWR is turned ON it will sound a warning when a launched radar guided missile is detected.

(-) Slew: *1*. This is an indication that the pilot is slewing the radar cursors to a target.

(C) Speed brakes. The speed brakes can have a value between 0 and 1.

(D) Steerpoint type: *STPT, IP, TGT*. This is the type of the steerpoint that has been selected. This is displayed on the steerpoint page of the DED.

(-) Sighting option: *VIP, VRP*. These options can be chosen when performing a CCRP or LADD attack.

(B) TACAN function: *TR, AA-TR*. This switch is used for specifying the kind of TACAN channel that has been set. This is either a channel on the ground (TR) or one in the air (AA-TR, e.g. a tanker aircraft).

(D) Throttle: *IDLE, MIL, MAX AB*. The throttle stick is located besides the left knee of the pilot. The RPM display is located on panel D.

(C) Throttle idle detent: *1*. This idle detent should be switched to enable the throttle stick to be moved below the idle position which will cause the fuel flow to the engine to stop.

(D) TWS (Threat Warning System). This is a panel on which the ML light is located as well as a scope that can display radar threats in the area.

(C) U/C. This is a panel located to the left of the ICP in the cockpit with a light for every part of the landing gear that indicates the status of the landing gear.

(G) UFC (Up Front Controls): *ON, OFF*. These controls are all the controls on the UFC panel. This panel is located right below the HUD on panel D and contains the ICP and the DED among other things.

(-) Wheel brakes: *ON, OFF*.

C.1 The Multi Function Displays

In the cockpit of the F16 are two displays called Multi Function Displays (MFD's) that show information about the stores on the F16 and the radar image among other things. It is with these two displays that the pilot can choose which kind of radar and which weapon to use. There are a lot of different pages that can be displayed on the MFD's but the most important ones are given below.

OFF.

Main. The main page is the starting point for navigating to other pages.

HSD (Horizontal Situation Display). The HSD displays a radar image of the surrounding area.

FCR (Fire Control Radar):

- OFF.
- STBY.
- RWS (Range While Searching). This radar mode is used for targeting with the AIM-120 and AIM-7 armament.
- VS (Velocity Search). This radar modes shows the velocity with which other aircraft are closing in on your position.
- TWS (Track While Scan). With TWS multiple targets can be tracked simultaneously.
- ACM (Air Combat Maneuvring). The ACM radar modes are used to point weapons.
  - NO RAD (Not Radiating): This is the default mode in which the radar is not radiating any radar beams.
  - HUD scan. With the HUD scan targets that are visible in the HUD can be locked.
  - Vertical scan. The radar beam is sweeped up and down in a vertical line.
  - SLW (Slewable scan). In this mode the radar pattern can be "slewed" (moved). This is the only ACM mode that can be used to lock up targets that can not be seen.
  - BSGT (Boresight scan). In this mode the radar beam is pointed straight out of the nose of the jet.
- GM (Ground Map). In GM mode the radar will see man made objects like buildings and bridges. The submodes of this mode are for adjusting the detail and magnification.
  - NORM (Normal)
  - EXP (Expand)
  - DBS1
  - DBS2
- GMT (Ground Moving Target). In GMT mode the radar will only detect moving objects like tanks and trucks.
  - NORM

  - EXP
- SEA (Sea mode). The SEA mode is used for detecting ships at sea.
  - NORM
  - EXP

SMS (Stores Management Systems) The SMS can be used to display information about the weapons and stores on board of the aircraft and to make a selection of those weapons.

- AAM (Air to Air Missile) page. On this page one of the AAM's can be chosen. The following missiles are examples of possible AAM's:
  - AIM-120 (AMRAAM). This is a radar guided, medium range missile.
  - AIM-9x: The AIM-9 is a heat seeking missile. The AIM-9P missile can only see the heat signature of an airplane if it is behind that airplane. The AIM-9M can see the heat signature from any direction.
  - AIM-7 (Sparrow). This missile is like the AIM-120, but unlike the AIM-120 the fighter has to stay locked on the target until the moment of impact.
  - A-A Gun (Vulcan cannon). There are several modes for the A-A gun:
    * EEGS (Enhanced Envelope Gun Sight). This mode will predict the target's position one bullet's time in the future.
    * LCOS (Lead Computing Optical Sight). This mode is like the EEGS but does not provide any prediction.
    * SNAP (Snapshoot Sight). In SNAP mode the HUD will display a snapshoot line that indicates where the gun has been pointing.
- AGM (Air to Ground Missile) page. What this page displays depends on the selected A-G missile. The following weapons are examples of AGM's:
  - Maverick. When the Maverick is selected the MFD displays an electro-optical image recorded by the missile's seeker head.
    * SLAVE. In the SLAVE submode the missile's seeker head is linked to the radar. This means the seeker head is always aimed at the object that has been locked by the radar.
    * BSGT (Boresight). In this submode the missile's seeker head is independent of the radar.
  - LGB (Laser Guided Bomb). When LGB is selected the MFD displays an electro optical image recorded by the missile's seeker head, just like when the Maverick is selected. For the LGB there are also the two submodes SLAVE and BSGT.
    * SLAVE
    * BSGT (Boresight)
  - HTS-HARM (HARM Targeting System, High-speed Anti Radiation Missile). The HARM missile has its own radar display, the HTS. The HARM missile can be fired at radar emitting targets at any direction from the aircraft. A HARM can for example be fired at a SAM site located behind the F16.
  - TARS (Tactical Aerial Reconnaissance System). The TARS can be used for gathering intelligence.

  - A-G bombs page. This page can be used to select one of the available A-G bombs. This page can also be used to select whether the bombs should be dropped singly or in pairs. The submodes are described extensively in chapter 3.
    - CCRP (Continuously Computed Release Point).
      - sighting option: VRP, VIP.
    - CCIP (Continuously Computed Impact Point).
    - DTOS (Dive Toss)
    - RCKT (A-G Rocket)
    - LADD (Low Altitude Drogue Delivery)
      - sighting option: VRP, VIP.
  - A-G Gun page.
- INV (Inventory) page. On this page an overview of everything that is loaded on the F16 is displayed.
- S-J (Selective Jettison) page. This page look like the INV page, but from this page stores can be selected to be jettisoned.

Appendix D

Glossary

A-A: Air to Air.

A-G: Air to Ground.

A-LOW: Automatic Altitude Low Warning.

A/C lights: Anti Collision Lights.

AAM: Air to Air Missile.

AB: Afterburner.

ACE: Adaptive Cockpit Environment.

ACM: Air Combat Maneuvring / Air Combat Mode.

AGL: Air Ground Level.

AGM: Air to Ground Missile.

AIM: Air Intercept Missile.

AMRAAM: Advanced Medium Range Air to Air Missile.

AOA: Angle Of Attack.

AR: Air Refueling.

AWACS: Airborne Warning And Control System.

BCN: Beacon mode.

BSGT: Boresight.

CCIP: Continuously Computed Impact Point.

CCRP: Continuously Computed Release Point.

DED: Data Entry Display.

DGFT: Dogfight.

DISC light: Disconnect light.

DL: Data Link.

DTOS: Dive Toss.

E-J: Emergency Jettison.

ECM: Electronic Counter Measures.

EEGS: Enhanced Envelope Gun Sight.

EPU: Emergency Power Unit.

EWS: Electronic Warfare System.

F-ACK: Fault Acknowledgment.

FCC: Fire Control Radar.

FCR: Fire Control Radar.

FLCS: Flight Control System.

FLIR: Forward Looking Infra Red.

FPM: Flight Path Marker.

FTT: Fixed Target Track.

GBU: Guided Bomb Unit.

GM: Ground Map.

GMT: Ground Moving Target.

GPS: Global Positioning System.

HARM: High-speed Anti Radiation Missile.

HSD: Horizontal Situation Display.

HTS: HARM Targeting System.

HUD: Head Up Display.

ICP: Instrument Control Panel.

IFF: Identify Friend or Foe.

ILS: Instrument Landing System.

INS: Inertial Navigation System.

INSTR mode: Instrument mode.

IP: Initial Point.

JFS: Jet Fuel Starter.

JMR: Jammer.

KCAS: Knots Calibrated Airspeed.

KIAS: Knots Indicated Airspeed.

KTAS: Knots True Airspeed.

LADD: Low Altitude Drogue Delivery.

LCOS: Lead Computed Optical Sight.

LGB: Laser Guided Bomb.

MFD: Multi Function Display.

MIL: Military Power.

ML: Missile Launch.

MLU: Mid Life Update.

MPO: Manual Pitch Override.

MSL: Mean Sea Level / Missile.

MSL OVRD: Missile Override.

NWS: Nose Wheel Steering.

PFD: Pilot Fault Display.

PFL: Pilot Fault List.

RP: Release point.

RALT: Radar Altimeter.

RCKT: Air to Ground Rocket.

RDY light: Ready light.

RWR: Radar Warning Receiver.

RWS: Range While Search.

S-J: Stores Jettison.

SLW: Slewable mode.

SMS: Stores Management System.

SNAP: Snapshoot Sight.

STBY: Standby

STPT: Steerpoint.

TACAN: Tactical Air Navigation.

TARS: Tactical Aerial Reconnaissance System.

TCN: see TACAN.

TD: Target Designator.

TGT: Target.

TWS: Track While Scan / Threat Warning System.

UFC: Up Front Controls.

VIP: Visual Initial Point.

VRP: Visual Release Point.

VS: Velocity Search.

Bibliography

Literature

[1] *Multi-Command Instruction 11-F16, (PACAF)Volume 3*, 21 April 1995.

[2] *Multi-Command Handbook 11-F16, Volume 5*, 10 May 1996.

[3] Microprose, *Falcon 4.0, the new benchmark in flight sim technology*, Microprose.

[4] Falcon Unified Team, *Falcon 4, Superpak 3, User Manual*, Infogrames Inc.

[5] Terrence P. Fries, "Consensus Development in Fuzzy Intelligent Agents for Decision Making".

Internet

[6] http://www.w3c.org/XML.

[7] http://www.w3c.org/XML/Schema.