F-35 Embedded Training

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ABSTRACT

The purpose of this paper is to provide an overview of Embedded Training (ET) in the Joint Strike Fighter (JSF). This paper will cover early ET concept development, the implementation of ET in JSF, now F-35 Lightning II, the pilot perspective of the ET training syllabus, and future development of F-35 ET. In the JSF concept development phase the training system solution included the deployable training device and added ET training capability built into the aircraft. ET was brought to the forefront with fighter pilots' heavy involvement in extended periods of aircraft deployment to international theaters of war. During these periods fighter pilots were away from continuation training opportunities. In response, the JSF training system concept integrated the ET Virtual Training Model (VTM) in the synthetic training environments to support "anywhere/anytime" interactive combat training while in-flight.

The objective of F-35 ET is to enhance and maintain fighter pilot proficiency. ET is implemented by functionally partitioning the aircraft integrated core processor (ICP). ET consists of the VTM hosted in the ICP and the P5 Combat Training System (CTS) contained in P5 Internal Subsystem (IS). Both VT and P5 CTS provide brief and debrief capabilities.

From the pilot perspective, VT is an overlay of constructive simulation on the real world to provide an enhanced training environment to the pilot. VT mission planning data is inserted in the aircraft via the preloaded portable memory device (PMD). A coordinated data link distribution of VT provides synchronization between a four-ship flight of F-35 aircraft. Pilots may train to a coordinated attack against virtual targets with appropriate threat reactions and kill responses that are shared across participants. All participating aircraft follow the same realistic, virtual pre-planned training scenario. Following the event, the pilot takes the PMD back to off-board mission support for debriefing. The result is combat team training in live flight supplemented and enhanced by a virtual combat environment.

1.0 INTRODUCTION

Lockheed Martin is developing the F-35 Joint Strike Fighter (JSF), the next generation strike fighter weapons system to meet an advanced threat (2010 and beyond) while improving lethality, survivability, and supportability over legacy platforms. The F-35 is a three variant family consisting of the Conventional Take Off and Landing (CTOL), the Carrier Variant (CV), and the Short Take Off and Vertical Landing (STOVL). The F-35, designated Lightning II, is a multi-role aircraft designed to execute critical air

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The purpose of this paper is to provide an overview of Embedded Training (ET) in the Joint Strike Fighter (JSF). This paper will cover early ET concept development, the implementation of ET in JSF, now F-35 Lightning II, the pilot perspective of the ET training syllabus, and future development of F-35 ET. In the JSF concept development phase the training system solution included the deployable training device and added ET training capability built into the aircraft. ET was brought to the forefront with fighter pilots heavy involvement in extended periods of aircraft deployment to international theaters of war. During these periods fighter pilots were away from continuation training opportunities. In response, the JSF training system concept integrated the ET Virtual Training Model (VTM) in the synthetic training environments to support anywhere/anytime interactive combat training while in-flight.

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defense and power projection missions. Built into F-35 is an Embedded Training (ET) capability that supports core missions such as counterair, air strike/interdiction, and suppression of enemy air defenses (SEAD). This paper provides an overview of F-35 ET capability covering early ET concept development, the implementation of ET in F-35, the pilot perspective of the ET syllabus, and future development of F-35 ET.

2.0 OVERVIEW

The F-35 ET consists of both a Virtual Training (VT) capability and a P5 Combat Training System (P5CTS) capability. VT extends the Embedded Combat Aircraft Training System (ECATS), developed by the National Aerospace Laboratory (NLR) and Dutch Space (DS). The P5CTS is being integrated to train pilots to effectively and efficiently employ the aircraft in a combat environment. Both VT and P5CTS include mission planning and debriefing capabilities.

VT provides the virtual threat software environment which executes preplanned threat scenarios supporting up to 4 virtual air threats (threat aircraft), 10 virtual surface threats (SAM sites) and associated virtual threat missiles, all of which can interact with and tactically engage the F-35. The VT capability is implemented as a software model that is hosted on the aircraft's integrated core processor (ICP). VT scenarios provide the training capability for preplanned and reactive threat responses for beyond visual range (BVR) training missions.

P5CTS/RedAir capability is provided on the F-35 as an integrated P5 Internal Subsystem (P5 IS). This training capability includes rangeless air combat maneuvering instrumentation (ACMI) supporting F-35 to F-35 interaction as well as legacy P5 dissimilar air combat training (DACT). Post mission debrief uses P5CTS recorded debrief data. A ground system provides live monitoring of training missions with uplink controls. Note: In order to use this training capability, ranges will need to be upgraded to the F-35 P5 IS standard.

3.0 EARLY EMBEDDED TRAINING CONCEPT DEVELOPMENT

During the JSF concept development phase, the training systems team found limited research literature on the training effectiveness of ET. In this phase they defined ET as a capability that could be integrated in the aircraft systems architecture to provide an advanced pilot training tool wherever the aircraft is deployed. For the pilot, ET would simulate realistic threats, targets, stores, and scenarios in conjunction with the air vehicle operational configuration without overriding established performance parameters. ET alternatives considered in the concept development phase included:

- Fully Embedded—Training capability is present or could be loaded as software on the operational equipment or hardware without use of additional hardware.
- Appended—Training capability requires attaching or connecting additional equipment or hardware to the operational equipment.
- Networked—Training capability requires electronic linking of individual systems to achieve the training objectives. Linked systems may be live, virtual or constructive.

4.0 ADVANTAGES AND DISADVANTAGES

Training advantages of ET were weighed against the cost impact to the training organizations. Identified advantages included the following:

- Reduces the number of support aircraft required by using virtual or constructive entities
- Eliminates the need to carry actual weapons during a training mission
- Provides training capability when an instructor is not present or readily available
- Can reduce need for installation of actual equipment in trainer aircraft

Potential disadvantages of ET included the following:

- Increase in procurement and sustainment costs
- Inadequate existing analysis limiting guidance for training effectiveness and efficiency
- Safety of flight or equipment impacts
- Increase in gaining unit operational budget

At that time, extended periods of aircraft deployment to international theaters of war limited pilots' access to resources required for continuation training, including proficiency and mission qualification training. In response, the JSF training system concept integrated the ET Virtual Training Model (VTM) synthetic training environment to support "anywhere/anytime" interactive combat training while in-flight. The desired approach to interactive combat training was modeled after existing live training exercises, such as the United States Air Force Red Flag exercise. Design included Blue and Red forces, mission planning, inflght interactive combat with air combat maneuvering instrumentation, and a robust debriefing capability.

5.0 DESIGN CHALLENGES

Design challenges for incorporating ET in the JSF aircraft included how to maintain safety of flight, how to transition between the virtual and live training environments, and how to provide meaningful training capability without exceeding onboard limits.

Safety-of-flight considerations were foremost in ET design. Software for ET would be partitioned from aircraft flight software to prevent interference with critical aircraft systems. Virtual weapon loads and responses would be partitioned from onboard weapon control. Accidental releases of real bombs would be inhibited by simulating all weapon employments onboard the aircraft while in TRAIN (ET ON) mode. Actual weapon releases would be prohibited in TRAIN mode and allowed only in the LIVE (ET OFF) mode.

ET architecture would require the ability to 'instantly' purge all virtual artifacts from the cockpit upon exiting TRAIN mode to restore the pilot's real world situational awareness in case of emergency or pilot disorientation. ET design included monitoring aircraft state in relation to both the virtual and the real training environment, so that aircraft (ownship) violations of real world 'hard decks' and preplanned safety boundaries would provide immediate, automatic transitions back to LIVE mode and termination of the training exercise.

The aircraft design mandated physical space and weight limitations as well as memory limitations on the additional ET capabilities. Consequently, ET software was to be designed to fit within existing aircraft integrated core processor (ICP) space limits, the virtual presentation to the pilot would use the same glass cockpit and aircraft controls as normal operations, and ET communications would use existing radio and data link communications systems. Scenarios generated for virtual training would be loaded via the same portable memory device (PMD) alongside the real world mission plans.

6.0 ET'S TIME HAS COME

Burkley, Slaton, and Neubert (1996) concluded from their review of ET system reports that recent technological advances showed that ET would overcome the challenges for implementing ET. They foresaw ET as becoming a key component of the total training system for the next generation of tactical aircraft. ET's time had come for JSF.

7.0 IMPLEMENTATION OF F-35 EMBEDDED TRAINING

ET was implemented in the aircraft by functionally partitioning VTM embedded simulations within the aircraft ICP. Air combat maneuvering instrumentation (ACMI) is integrated via the P5 Combat Training System (CTS), a missionized internal subsystem (IS) to provide an on-board 'rangeless' live combat training capability. The notional ET partitioning diagram is shown in Figure 1. ET TRAIN mode enables the pilot to train with real aircraft as surrogate threats or with computer-generated targets. The off-board mission support environment (OMSE) used to create, edit, and store ET Scenarios. Scenarios are then loaded into the PMD and transferred to the aircraft as a mission pilot-selectable data.

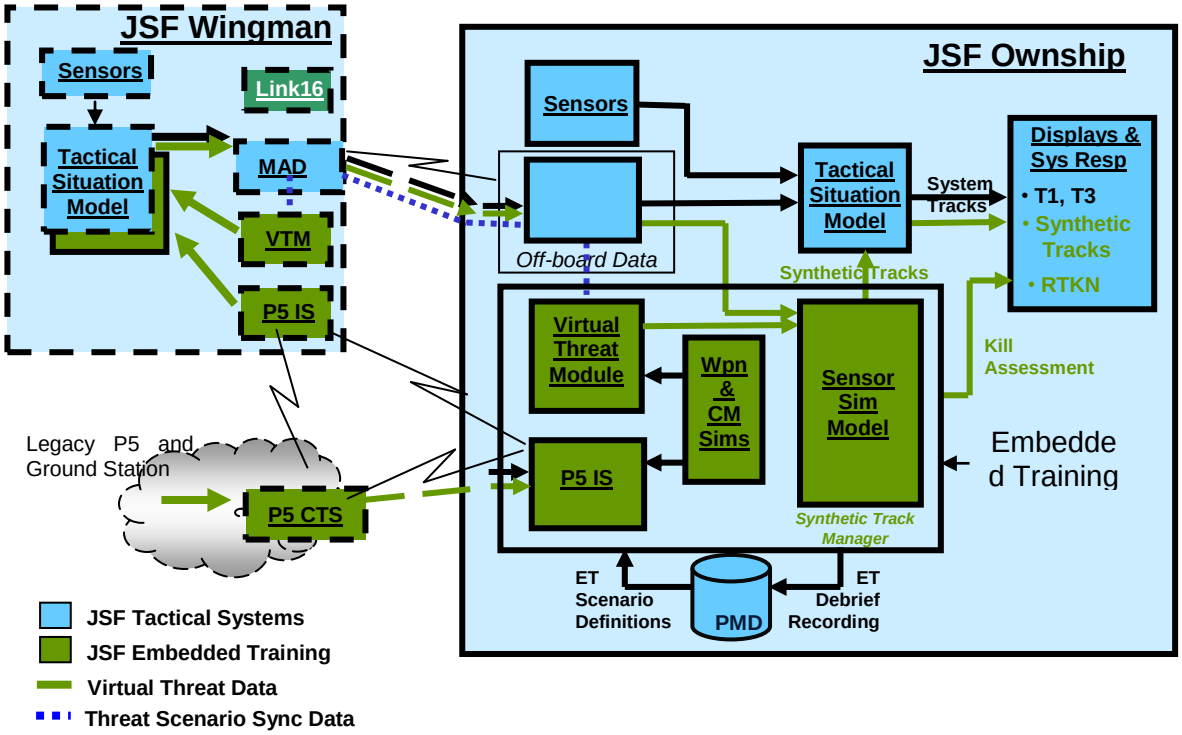

Figure 1. F-35 Embedded Training Block Diagram

8.0 F-35 ET TRAIN MODE

F-35 ET is activated when the pilot selects TRAIN mode from the pilot vehicle interface (PVI), which enables weapon and expendable countermeasures employment simulations. From TRAIN mode the pilot can access interactive combat training through an ET Scenario option. The RedAir Scenario option uses the P5 range instrumentation exercise to engage real aircraft as threats. The Virtual Threat (VT) Scenario option engages training using the on-board synthetic threat environment. Cockpit aural cues inform the pilot of the scenario state during execution. Both options have debriefing tools, independent capabilities that support the important after action reviews.

The inflight training scenario options of RedAir and VT can be executed independently as mutually exclusive exercises or they can be run concurrently as a combined exercise.

Virtual Threat. The ET Context Diagram in Figure 2 shows the flow for how missions planned with ET Scenarios are supported by the ET VTM and the P5 Internal Subsystem. The VT capability uses a simulation model that provides a virtual training environment overlay on the real world, supporting deployable, on-demand ("anywhere/anytime") interactive combat training while inflight. This model executes threat scenarios containing interactive virtual surface and air threats for use in training combat tactics. VTM supports single-ship as well as multi-ship exercises up to a four-ship configuration. Multi-ship exercises allow each participating F-35 aircraft to interact in a coordinated engagement with the same simulated air and surface threats. Coordination among the multi-ship is performed using the F-35 data link multifunction advanced datalink (MADL).

Each virtual surface or air threat can support engagement simulation by modeling dynamic threat missile flyout. Virtual missile flyout can be employed against participating F-35 aircraft and provide real-time 'kill assessment' (RTKA) of the participating aircraft. In addition to RTKA determination, virtual missile flyout simulations produce synthetic system/missile tracks which are represented on the aircraft cockpit displays alongside real tracks. RTKA results in a Hit or Miss determination and stimulates an aural and visual notification of "Ownship Killed" to the pilot under missile attack, removing the killed aircraft from the training scenario. F-35 simulated missile launches against virtual threats are also assessed using a basic kill probability, resulting in removal of the virtual threat when a kill is determined. The virtual surface and air threat simulations may be programmed to provide defensive (air threats only) or offensive response based on a variety of triggering conditions, such as F-35 detection, missile launch, scenario time, or geographic position.

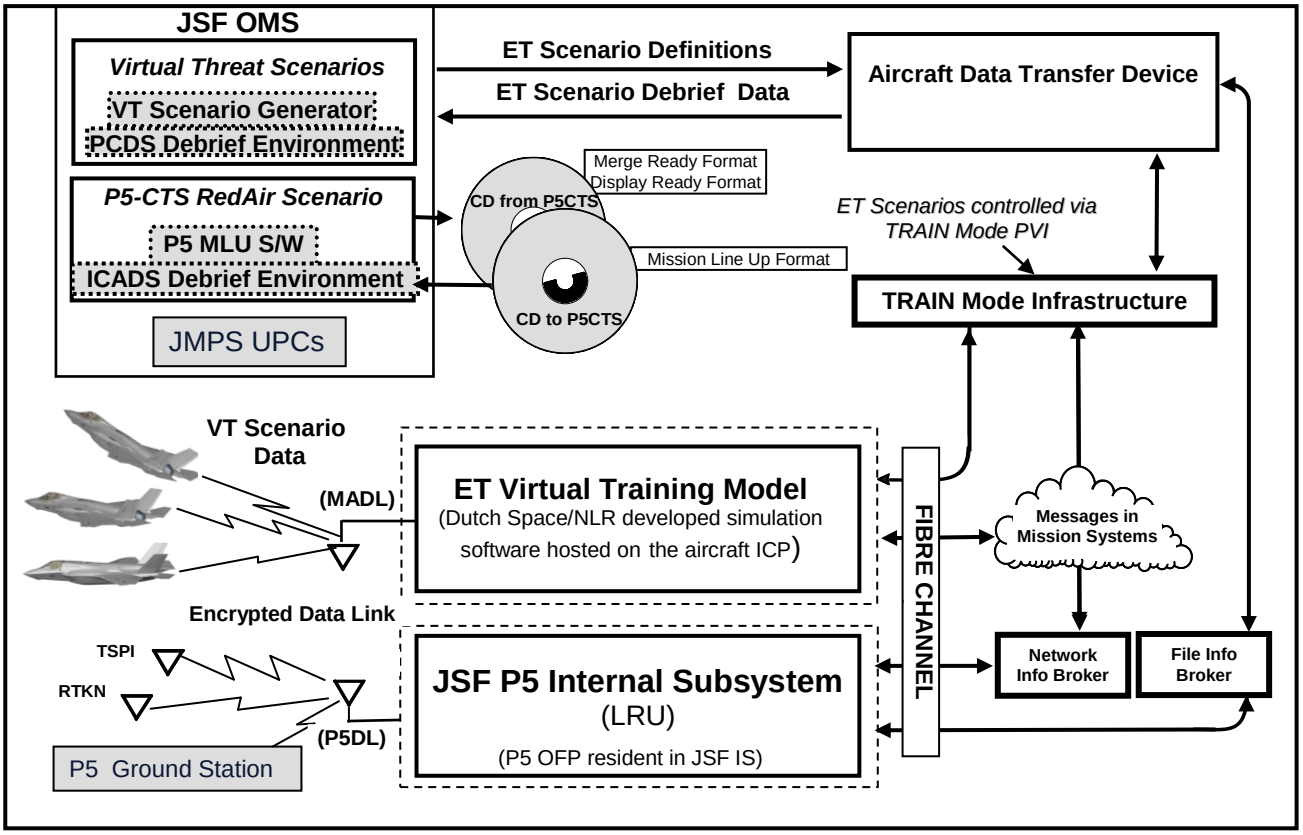

Figure 2. F-35 Embedded Training Context Diagram for Virtual Threat and RedAir Scenarios

The embedded VTM software generates the VT Truth Data which is used by the ET Fusion Simulation Model (ET FSM) to produce all-in-one (AIO) pre-correlated fused Synthetic System/Missile Tracks. ET FSM will send/receive Synthetic System Tracks over MADL between F-35 VT Scenario participants. ET FSM will be able to correlate (merge) on-board with off-board MADL Synthetic System Tracks. ET FSM will assign combat identification/rules of engagement (ID/ROE) to the synthetic threat missile. The ET FSM provides its air Synthetic System/Missile Tracks to the air-to-air (AA) Tactical Situation Model (TSM) for processing, while its surface Synthetic System Tracks are provided to the air-to-surface (AS) TSM for processing. Currently, no virtual threat or threat missile data is provided via the P5 IS (i.e. no synthetic tracks are generated via a P5 RedAir Exercise); however, F-35 kill status may be shared across VT and P5 exercises.

During the VT scenario execution, scenario states, events, and virtual entity dynamics will be recorded. These recording are to support a comprehensive post-mission debrief and scenario playback.

9.0 PILOT PERSPECTIVE OF EMBEDDED TRAINING

From the pilot perspective, VT is an overlay of constructive simulation on the real world to provide an enhanced training environment to the pilot. VT mission planning data is inserted in the aircraft via the preloaded PMD. A coordinated data link distribution of VT provides synchronization between a four-ship flight of F-35 aircraft. Pilots may train to a coordinated attack against virtual targets with appropriate threat reactions and kill responses that are shared across participants. All participating aircraft follow the same realistic, virtual pre-planned training scenario. Following the event, the pilot takes the PMD back to off-board mission support for debriefing. The result is combat team training in live flight supplemented and enhanced by a virtual combat environment.

10.0 F-35 ET ACTIVITY

The F-35 activity model is depicted as three events. These activities start with Plan ET Event (1.0) which results in the PMD Load. The next activity is Fly ET Event (2.0) which provides output to the PMD. The final activity is Debrief, Grade and Report ET Flight Event (3.0).

Plan ET Event (1.0). The Joint Mission Planning System (JMPS) enables planning of both VT and P5 scenarios. A Scenario Generation Tool (SGT) provides VT Scenario planning. The P5 Unique Planning

Component (UPC) is used to plan P5 missions, also known as ‘RedAir’ Exercises, via the Mission Line Up (MLU) tool. Geographic Safety Boundaries may be defined to limit application of the synthetic training environment for safety of flight considerations. In TRAIN mode, engagement simulation is provided by modeling the actual weapons inventory characteristics. In addition, virtual weapons can be simulated on empty stations, to allow for training with a wide range of air-to-air and air-to-ground weapons. Real and virtual weapons can simultaneously co-exist in the inventory for seamless employment training. During the event, virtual weapons decrement on simulated employment, while real weapons always represent the actual inventory count.

Models use tabularized parameters that include the capability to tailor classification levels by country or service. When the ET event plan is complete, scenarios, participants, and other data are loaded on the PMD for transfer to the F-35 aircraft.

Fly ET Event (2.0). When the PMD is docked in the F-35 aircraft, the pilot can fly the ET event. The pilot selects TRAIN mode to initiate ET. For VT events, the pilot selects an ET option. For coordinated VT scenarios, the flight lead selects a preloaded scenario (VT 1, VT 2, VT 3, or VT 4), while wingmen select VT Group. This allows the flight lead to select the training scenario without wingmen knowledge for

instructional purposes. The scenario is then executed by the flight lead selecting VT Run, which is announced to all scenario participants.

In VT mode training, the pilot can:

- Detect synthetic threats using All-In-One (AIO) Sensor Model, including simulation of Radar, ESM, and DAS sensor perspectives
- Engage and destroy synthetic air threats (less than or equal to 4 threats) based on preplanned scenarios defined in mission planning, to include route to be flown and planned reaction
- Engage and destroy synthetic SAM sites (less than or equal to 10 sites) defined in mission planning to include loadout and planned reaction
- Defeat incoming missiles with maneuvering and counter measures.

During the ET flight event, a mix of both real and virtual weapons can be loaded into the inventory. Real and virtual weapons are distinguished on the stores management display by different colors. In TRAIN mode all weapon releases, whether a real or virtual weapon has been selected for deployment, are simulated. As weapons are released, virtual weapon quantities in inventory will be decremented on the stores management page while the real weapon quantities will not decrement. Weapons bay door operations are normally simulated, but a pilot-selectable option is provided to allow for actual weapons door actuation. In TRAIN mode, the pilot may also select either a real or simulated countermeasure (CM) inventory. The CM inventory will decrement upon usage for virtual and real inventories. However, the CM dispenser doors on the aircraft will not open during simulated CM expenditure.

Ownship kill criteria are defined within the ET scenarios. These criteria can be tailored to specific training objectives. For VT successful threat missile flyout (with no F-35 reaction) will likely result in a kill notification. However, it is possible for a valid shot not to result in a kill, as a probabilistic determination is included in kill assessments. VT kill notification is shared with all flight members. Members will see the killed participant represented by a coffin symbol superimposed on the F-35 symbol presented on participant cockpit displays. When F-35 missile launches against synthetic threats are assessed as kills, the killed target symbol is removed. Note: Kinematic flyouts of ownship missile launches are not currently modeled.

P5 CTS events are initiated when the pilot selects REDAIR mode. For P5 CTS, when missile flyout results in a kill assessment, kill notification is provided to the targeted aircraft. Real-time engagement simulation requires precise position determination, therefore, aircraft equipped with unencrypted legacy P5 CTS systems will be unable to assess kills against F-35 aircraft in real-time.

Debrief, Grade and Report ET Flight Event (3.0). Post flight, pilot data is merged to support integrated mission debrief. Different debrief environments have been defined for P5 CTS and VT scenarios to provide compatibility with the existing P5 debriefing system. P5 CTS uses the Individual Combat Aircrew Display System (ICADS), while both P5 and VT may use the Personal Computer Debriefing System (PCDS).

Table 1. F-35 Embedded Training Cost Avoidance Implementing Activity Model

	($M)	Air to Air	Air to Ground	Total
Start Up	CY15	$67.6	$21.6	$89.2
	CY16	$103.3	$30.8	$134.1
	CY17	$146.5	$41.7	$188.2
Steady State	CY30	$775.5	$270.5	$1,046.0
Life Cycle	CY13-57	$2,370.0	$606.0	$2,976.0

11.0 ET COST AVOIDANCE

Implementation of the F-35 ET activity model has projected program savings shown in Table 1. In terms of student costs, the projection reduction is 14 Red Air sorties, equivalent to 23.8 flight hours for $100k, and SAM/EW range reductions of 7.2 hours for $25.5k. Looking at start up, calendar years 2015 through 2017, the projected cost avoidance is $411.5M. When the F-35 reaches steady state at calendar year 2030, the projected cost avoidance is $1,046M. Over the expected life cycle of calendar years 2013 through 2057, the program savings could reach $2,976M.

12.0 FUTURE DEVELOPMENT OF F-35 ET

Modern forces must train as they operate. Since our forces operate together as a cohesive unit, our training capabilities must have the same characteristics. DOD Directive 1322.18 (January 13, 2009) states that "training realism shall be maximized through use of the live training domain supplemented by integrated virtual and constructive capabilities," including integration of joint and service virtual and constructive simulations, opposing force capabilities, and range instrumentation.

The F-35 training development strategy provides architecture for achieving integrated, distributed training within live, virtual, and constructive (LVC) environments. Key constituents to achieving this LVC strategy include distributed network connectivity, improved training instrumentation, and enhanced ET capabilities. These ET enhancements will extend existing embedded constructive-scenario generation with on-aircraft simulation support services. This extension includes the capability to generate sensor perspectives of simulation entities and to communicate aircraft state data for representing the aircraft as a simulation entity in LVC domains.

Achieving integrated, distributed ET within LVC environments will take coordinated development based on common training architectures. This achievement will also take open, net-centric, interoperable standards. Using these achievements, developers will not only achieve interoperability with the existing training infrastructure, but will also provide the foundation for forward-compatibility with emerging and evolving enterprise training solutions. This vision of the future puts ET within LVC for service, joint, and coalition training.

13.0 SUMMARY

The F-35Embedded Training (ET) consists of both a Virtual Training (VT) capability and a P5 Combat Training System (P5CTS) capability. VT extends the Embedded Combat Aircraft Training System (ECATS), developed by the National Aerospace Laboratory (NLR) and Dutch Space (DS). The P5CTS is being integrated to train pilots to effectively and efficiently employ the aircraft in a combat environment. Both VT and P5CTS include mission planning and debriefing capabilities.

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P5CTS/RedAir capability is provided on the F-35 as an integrated P5 Internal Subsystem (P5 IS). This training capability includes rangeless air combat maneuvering instrumentation (ACMI) supporting F-35 to F-35 interaction as well as legacy P5 dissimilar air combat training (DACT). Post mission debrief uses P5CTS recorded debrief data. A ground system provides live monitoring of training missions with uplink controls. Note: In order to use this training capability, ranges will need to be upgraded to the F-35 P5 IS standard.

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ET is becoming a key component of the total training system for the next generation of tactical aircraft. Over the expected life cycle of calendar years 2013 through 2057, the program savings could reach $2,976M.

This vision of the future makes ET an important factor in achievement of LVC service, joint, and coalition training. ET's time is here.

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