Introduction and Overview

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Syllabus

- The students in this course will be applying systems engineering principles in the context of understanding various weapons systems and their relationship to the overall combat system. Aerodynamics, guidance laws, missile design, control loops, track filtering, coordinate systems, and in-flight control of missile systems will be studied.
- Many of the concepts discussed are not unique to missiles and can be extended to the more general class of projectile weapons. An attempt will be made to broaden the scope of the lecture when appropriate to provide a fuller understanding of weapon systems with projectiles.

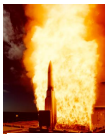

Figure © Lockheed Martin

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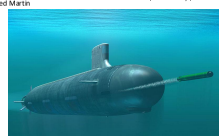


(U.S. D.O.D. Graphic by Ron Stern/Released) / Public Domain

Combat Systems

- The allocation of weapon system and combat system responsibilities are often blurred
  - This is advantageous as it will allow us to explore either side of the combat system / weapon system divide
- A combat system can have more than one weapon system
  - Multiple weapon systems in a combat system provide capability across mission areas
  - The combat system is ultimately responsible for assigning a weapon system to a specific task (or potential threat)
- Combat systems must balance risk and reward
  - Assisting in the selection of a specific weapon system for a specific engagement
  - i.e. Don't use a cannonball to kill a fly

Large Combat Systems Often Have Multiple Weapons Systems

Multiple Weapon Systems in a Combat System

Illustration taken from reference 2

The Weapons System Basics

- A weapon system is a collection of components (hardware and software) necessary to support the specific functionality of a weapon (or weapons)
- The weapon system includes three major components
  - Sensors (target tracking)
  - Decision processing
  - Weapon control system
- Each of the three components have a specific function in the weapon system

Component	Function	Purpose
Sensor	**Detect**	Find and track objects
Decision Processing	**Control**	Determine if action is needed against an object
Weapon Control System	**Engage**	Neutralize the object

Detect, Control, Engage are the Major Functions of the Weapon System

Detect

Weapon System Basics

- **Detect** - A means to determine if an object is present
  - Diverse methods may be used to determine what is present in its area of operation
- Weapon systems require awareness of the surroundings
  - Where are the assets the weapon system is to defend?
  - Where are the objects that are a potential threat?

Organic Sensors

- Radar, IR, optics
- Passive listening devices (Electronic Warfare)

http://www.smdc.army.mil/SMDCPhoto_Gallery/Sensors/Sensors.html / Public Domain

Network Information

- Data link
- Voice (telecommunications)
- Intelligence

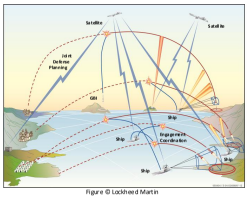


Figure © Lockheed Martin

Track
Detect

- Regardless of how an object is detected, the combat system must revisit the object periodically to give the warfighter the best overall description of the area
  - Some times the object is a willing participant
    - Active broadcasts (IFF, PPLI, missile communications, etc.)
  - Sometimes the object is not a willing participant and reliance upon various sensors and networks is required to keep a constant flow of information on the object
    - Unidentified objects
    - Threats
    - Low observable (stealth) objects
- Multiple contacts from an individual object are turned into tracks using all the data provided to the combat system regarding that object
- The track is used by the combat system command and control system to make suggestions regarding combat system operations

Control
Weapon System Basics

- Purpose
  - Define how the system should be configured to support the mission
  - Sharing of information across networks (when applicable)
- Information available
  - All organic sensor reports (or tracks)
  - A hub for all network information
  - Input from the warfighter (customization)
- Determines course of action
  - Decisions regarding a presence of an object
  - The object must be classified, categorized, and/or identified
  - Monitor the object's trajectory and ancillary data on a consistent (periodic) basis

Responsibilities
Control

- **Control** – Use rules of engagement and decision process to determine a course of action
  - Observe: Collect as much information as possible / intelligence to classify, categorize and/or identify the object
  - Orient: Put the information in the proper context
  - Decide: Determine if something should be done about the object
  - Act: Take action against the object

This process model was developed by Col. John Boyd (USAF) during the Korean War and is still used today

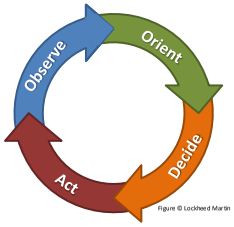


Figure © Lockheed Martin

Observe
Control

- Collect as much information as possible
  - Within the weapon system
  - Within the combat system
  - Across other systems or platforms
- Knowing which information to continually monitor is crucial to efficiency and success of the system
  - Information is constantly being received from sensors, networks, and from human interaction

The Periodic Monitoring of Information Provides the Weapon System the Most Accurate Information from which to Make Decisions

Orient
Control

- Determine what this information means to you (the warfighter, operator, etc.)
- Situational awareness
- Threats and unidentified objects
  - Track kinematics and /or measurements
  - ID data
  - Ancillary data
- Coordination
  - Battle planning, battle management
  - Engagement status

Information is Only Useful if Put in the Proper Context

Decide
Control

- Consider the options available given the orientation of the information available
- The criteria used for this decision is a set of rules called the "rules of engagement"
  - Assists in the determination of a threat
  - Determine how to proceed given an object is determined to be a threat
    - Take no action at this time
    - Action is required
      - Example 1: Alert the warfighter to the threat
      - Example 2: Engage the threat autonomously
- Most systems allows the warfighter to over-ride default rules
  - Apply additional set of rules, or
  - Determine a specific course of action for a specific object

Act
Control

- The rules of engagement will determine if the weapon system should perform some action
- There are a wide range of actions that can occur. A very small subset of actions that can be performed on a specific object include
  - Update an object ID
  - Request more data on a specific object
  - Provide an alert to the warfighter
  - Engage a threat
  - Report on the engagement status of a threat
  - Terminate an engagement
- The action of engaging a threat is the action that is most relevant to our discussion as it will result in a weapon being used the negate the threat

Information Regarding the Engaged Threat is Passed to the Weapon Control System

Engage
Weapon System Basics

- **Engage** - A means to neutralize the object with a specific weapon
  - Selecting a specific weapon for the specific threat
  - Supporting the weapon throughout the engagement
  - Evaluate the successfulness of the weapon at the end of the engagement

https://en.wikipedia.org/wiki/MIM-104_Patriot / Public Domain

Missile

U.S. Navy photo by Mass Communication Specialist 2nd Class Derek J. Hurder (Released) / Public Domain

Torpedo

U.S. Navy photo by Photographer's Mate Airman Kenny Swartout (RELEASED)/ Public Domain

Gun

Types of Weapon Systems

- Weapon systems are tailored to specific threat types and environments
- Types of warfare
  - Anti-Air Warfare (AAW)
  - Anti-Surface Warfare (ASuW)
  - Anti-Submarine Warfare (ASW)
- Each mission type requires a weapon with unique characteristics
  - Max range
  - Speed
  - Maneuverability
  - Onboard Sensors

Figure © Lockheed Martin

Weapons are Designed to Be Effective for Specific Mission Areas

Weapons

- Weapons are tailored to specific missions areas
  - Weapons are designed to be effective against specific threat types
  - Capability of a specific weapon against other threat types may not exist
  - There is no such thing as a "one size fits all" weapon
- Missions are described by the environment and the threat type
  - Environment (Land, Sea, Air, Cyber)
  - Threat type (Projectile, Vehicle, People, Electronic Attack)
- Environment of the threat must be considered for each weapon
  - Capability from a specific environment to another may not exist
    - Ex. - Weapons that work well under water do not work well above water
- The most extensive group of weapons in use is the projectile
  - This course will focus on weapon system design for projectile weapons

Projectile Weapons

- Projectile weapons have been around for over 100,00 years
  - For the majority of that time, the weapon range/lethality was limited by the power generated by a human
- The invention of black powder by the Chinese allowed for projectiles to be fired over longer distances with greater speed at impact
  - Weapon range/lethality is limited by the amount of energy in the explosive
  - The invention of black powder marks the beginning of the modern weapon era even though it isn't used in warfare for hundreds of years

"Modern" Projectile Weapons	Examples	Propulsion	Guidance
Simple Projectiles	Sling shot, spear, arrow	No	No
↳ "Propulsion Projectiles"	Cannonballs, bullets	**Yes**	No
Rockets	RPG, bazooka	**Yes**	No
↳ **Missiles**	**AMRAAM, Hellfire, etc.**	**Yes**	**Yes**

Projectiles, Rockets, and Missiles

- The simple projectile has no propulsion system
  - It's maximum speed is at launch
- Both the missile and the rocket have at least one propulsion system
- A missile is a rocket that can be guided during flight
- Studying missile systems will encompass both projectiles and rocket systems as well

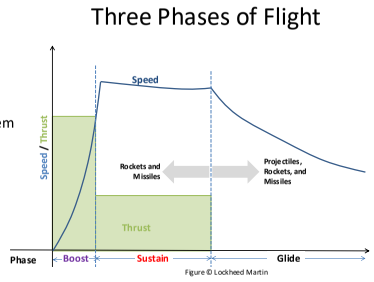


Figure © Lockheed Martin

What Were the Key Events that Led to the Development of the Modern Missile?

History of the Modern Missile
Part I

- 7th Century, China
  - Rocketry invented with the discovery of black powder
  - Consists of salt peter, sulfur, arsenic, honey
  - Used to propel arrows from crossbows
- 13th Century
  - 1232, Battle of Pien-King (Chinese vs. Mongols)
    - First large scale battle using rocketry
  - Mongol invasion brings black powder to Europe
  - The fire arm is invented in China
  - Cannons invented in Europe
- 14th Century
  - Handheld cannons (or guns) are developed in Europe

Developing the Science of Rocketry was a World Wide Endeavor

History of the Modern Missile

- At this point, hand guns were "cutting edge" technology, but were inferior to the traditional projectile weapons
  - Guns were unable to penetrate armor where as a long bow arrow or crossbow bolt could

Eugene Viollet-le-Duc / Public Domain

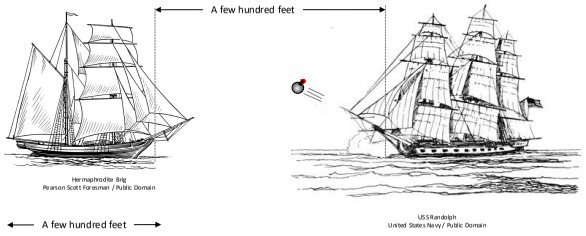
Encyclopedie Larousse / Public Domain (U.S.)

History of the Modern Missile
Part II

- 14th - 15th Century
  - Propulsion aided projectiles reliability improves
    - Accuracy and lethality match or exceed an archer's capability
    - Limited firepower (long time to reload) still an issue
  - Optimal mixture of black powder components is determined
    - Maximizing the energy per ounce of powder

History of the Modern Missile
Part III

- 15th Century, Spanish vs. Turks
  - Victorious Spanish navy credited with using cannons for this first time in naval warfare
  - Poor accuracy required a distance of a few hundred feet for the cannon to be effective



Hermaphrodite Brig
Pearson Scott Foresman / Public Domain

USS Randolph
United States Navy / Public Domain

History of the Modern Missile
Part IV

- 1650 – First guided missile is proposed
  - Konrad Kyser von Eichstadt proposes a rocket guided to a target by traveling along a chord
- Early 1800s, Britain (Congreve rocket)
  - Iron castings introduced and replaced paper castings
  - First use of rockets for bombardment (Britain vs Napoleonic France)
- 1846, Britain
  - William Hale invents the spin stabilized rocket
  - Stabilization of rockets during flight is poor
    - Stabilization is provided by extending a stick from the aft end of the rocket
- Late 1800s
  - Concept of the nozzle is introduced
  - Addition of wings for stability
  - Advances in fields of thermodynamics and fluid flow theory
- WWI
  - Rockets still not as accurate as artillery
  - Artillery still dominates air weaponry

Finally, Missiles! – World War II
Evolution to Modern Missiles

- Guidance techniques were introduced (thus missiles were born)
  - Preprogrammed guidance with a mechanical autopilot
  - Radar controlled (beam rider) guidance
  - Proportional navigation
  - Project Orcan (BF Skinner's organically controlled, pigeon guidance)
    - Until recently pigeon guidance was an official guidance designation in U.S. military descriptors
    - The project was never put into tactical use, but it was viewed as a successful novelty by the US military
- Many different countries used tactical rockets and missiles during World War II
  - Success varied by program and country

Rockets / Missiles in World War II

Evolution to Modern Missiles

- Germans
  - V-2 liquid propelled rocket with 1650 pound warhead
    - 200 mile range (greater range than artillery)
    - First man-made object in space
  - HS293 air launched, solid propelled, radio controlled anti-ship rocket
  - ME163 (Komet) liquid propelled aircraft interceptor
- Japanese
  - Yokosuka MXY-7 *Ohka* (nicknamed the "Baka" or "idiot" bomb)
    - Air launched, 3 solid rocket motors, piloted anti-ship glide bomb
- Russians
  - Katusha artillery rocket
- U.S.
  - Bazooka

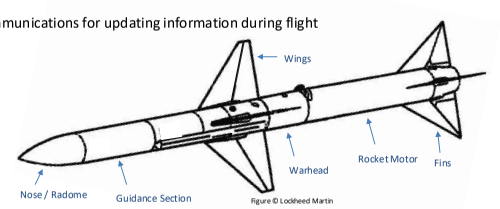
Start of Modern Missile Programs

Evolution to Modern Missiles

- German missile programs were deemed a major threat by the U.S.
- To counter the threat of enemy guided missiles, the U.S. government stood up a task force in 1944 to develop a plan to defend against missile threats
  - Led by Johns Hopkins University
  - Bumblebee program initiated in February, 1945
    - Supersonic guided missile
    - Ramjet and/or solid state propellant
    - Advanced endgame techniques
      - Fuze
      - Proximity warhead
- The missiles of the era have the basic components of today's missile
  - Propulsion
  - Guidance/Navigation System
  - Sensors
  - Warheads

Modern Missiles

- Propulsion systems
- Guidance systems
  - Different guidance modes for different phases of flight
  - Greater accuracy against stationary and moving threats
- Proximity fuze (and warhead) provide capability against air threats such as missiles and aircraft
- Communications for updating information during flight



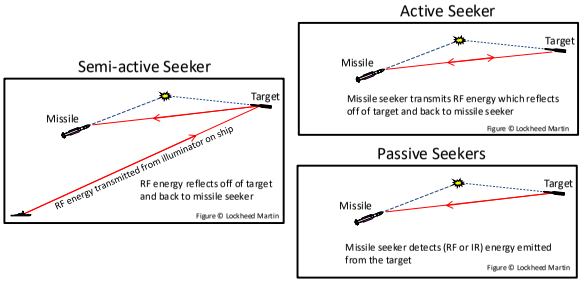
Missile Types

- The difference in threat capability has a profound affect on the design on the weapon and the weapon system
  - Missile and weapon systems are highly specialized
- Specialization is based upon the threat the system is designed to defeat

Missile Type	Threats	Missile Characteristics
Surface to Air Missile (SAM)	• Air targets • Ballistic Reentry Vehicles • Can maneuver to avoid intercept	• High speed • High maneuverability • Highly reactive
Air-to-Air Missile (AAM)		
Surface-to-Surface Missile (SSM)	• Ground targets • Surface ships	• Accurate inertial systems • Low maneuverability • Speed is a function of desired range and ability to defeat defense system
Air-to-Surface Missile (ASM)		

Missile Seekers

- All missiles (except for missiles with preprogrammed guidance systems) use a seeker to find the intended target
  - A seeker is a sensor located near the nose of the missile
  - Seeker detected RF or IR energy reflecting or radiating from the target



Weapon Control Systems

- The weapon control system (WCS) is the brains of the engage function
- At a bare minimum WCS will
  - Determines what weapon is to be used
  - When to fire the weapon
- Weapon Control Systems support general classes of weapons
  - Simple projectiles ("wooden rounds")
  - Intelligent weapons

Characteristic	Simple Projectile	Intelligent Weapon
Propulsion	Doubtful	Almost always
Shelf life	Nearly infinite	Limited
Moving parts	No	Yes
Electronics	No	Yes
WCS Complexity	Low	Medium to high

Weapon Control System Complexity

- Intelligent weapons need more support from the WCS than simple projectile weapons
- Additional weapon support may include
  - Inflight monitoring & tracking
  - Guidance support
  - Weapon reference unit alignment aids
  - Handover support
    - Scheduling of additional resources
    - Target cue updates
  - Engagement assessment
    - Success / fail
    - Relaunch decision

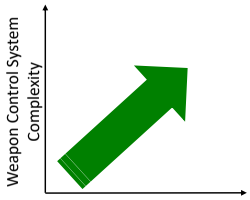


Figure © Lockheed Martin

WCS Complexity Increases as Weapon Complexity Increases

Weapon Control Systems for Missiles

- Missiles are only activated when they are to be fired
  - Safety concerns prohibit applying power to a missile without intent to launch
  - Limited battery life (minutes to hours)
- All missiles require a support system prior to launch
  - Inventory replenishment
  - Initialization data
  - Protection from the elements
- The amount of support required by a missile after launch varies greatly
  - Fire and forget missiles require no support
  - Slaved guidance missiles are part of a feedback loop which is tightly coupled to the weapon control system and typically has a high rate of information transference
- WCS is designed to support a missile both prior to, and after, launch

Up Next….

- A Weapon Control System's responsibilities vary with the weapon type it supports as well as the mission area for which the system is designed
  - Our focus will be on weapon systems designed to support missiles
  - Basic understanding of a missile is required before we can study a missile-based weapons control system
- Next week, we will begin our study of weapons by giving an overview of airframes and missile aerodynamics

References

1. Missile System Engineering Fundamentals, Lockheed Martin Lectures (circa ~1984).
2. NAVEDTRA 14110, *Gunner's Mate 1 & C*. November 1996

BACK UP

Project Orcan's Legacy

Naval "AN" Equipment Indicator System

SET OR EQUIPMENT INDICATOR LETTERS

AN / S P Y 1 A
"AN" SYSTEM | WHERE IT IS | WHAT IT IS | WHAT IT DOES | MODEL NO. | MOD. LETTER

INSTALLATION | TYPE OF EQUIPMENT | PURPOSE

A – AIRBORNE (INSTALLED AND OPERATED IN AIRCRAFT).
B – UNDERWATER MOBILE, SUBMARINE.
C – AIR TRANSPORTABLE (INACTIVATED, DO NOT USE).
D – PILOTLESS CARRIER.
F – FIXED.
G – GROUND, GENERAL GROUND USE (INCLUDES TWO OR MORE GROUND-TYPE INSTALLATIONS).
K – AMPHIBIOUS.
M – GROUND, MOBILE (INSTALLED AS OPERATING UNIT IN A VEHICLE WHICH HAS NO FUNCTION OTHER THAN TRANSPORTING THE EQUIPMENT).
P – PACK OR PORTABLE (ANIMAL OR MAN).
S – WATER SURFACE CRAFT.
T – GROUND, TRANSPORTABLE.
U – GENERAL UTILITY (INCLUDES TWO OR MORE GENERAL INSTALLATION CLASSES, AIRBORNE, SHIPBOARD, AND GROUND).
V – GROUND, VEHICULAR (INSTALLED IN VEHICLE DESIGNED FOR FUNCTIONS OTHER THAN CARRYING ELECTRONIC EQUIPMENT, ETC., SUCH AS TANKS).
W – WATER SURFACE AND UNDERWATER.

A – INVISIBLE LIGHT, HEAT RADIATION.
B – PIGEON.
C – CARRIER.
D – RADAC.
E – NUPAC.
F – PHOTOGRAPHIC.[1]
G – TELEGRAPH OR TELETYPE.
I – INTERPHONE AND PUBLIC ADDRESS.
J – ELECTROMECHANICAL OR INERTIAL WIRE COVERED.
K – TELEMETERING.
L – COUNTERMEASURES.
M – METEOROLOGICAL.
N – SOUND IN AIR.
P – RADAR.
Q – SONAR AND UNDERWATER SOUND.
R – RADIO.
S – SPECIAL TYPES, MAGNETIC, ETC., OR COMBINATIONS OF TYPES.
T – TELEPHONE (WIRE).
V – VISUAL AND VISIBLE illumination taken in TOGETHER.
W – ARMAMENT (PECULIAR TO ARMAMENT, NOT OTHERWISE COVERED).
X – FACSIMILE OR TELEVISION.
Y – DATA PROCESSING.

A – AUXILIARY ASSEMBLIES (NOT COMPLETE OPERATING SETS USED WITH OR PART OF TWO OR MORE SETS OR SETS SERIES).
B – BOMBING.
C – COMMUNICATIONS (RECEIVING AND TRANSMITTING).
D – DIRECTION FINDER, RECONNAISSANCE, AND/OR SURVEILLANCE.
E – EJECTION AND/OR RELEASE.
G – FIRE-CONTROL OR SEARCHLIGHT DIRECTING.
H – RECORDING AND/OR REPRODUCING (GRAPHIC METEOROLOGICAL AND SOUND).
K – COMPUTING.
L – SEARCHLIGHT CONTROL (INACTIVATED, USE G).
M – MAINTENANCE AND TEST ASSEMBLIES (INCLUDING reference 2
N – NAVIGATIONAL AIDS (INCLUDING ALTIMETERS, BEACONS, COMPASSES, RACONS, DEPTH SOUNDING, APPROACH, AND LANDING).
P – REPRODUCING (INACTIVATED, DO NOT USE).
Q – SPECIAL, OR COMBINATION OF PURPOSES.
R – RECEIVING, PASSIVE DETECTING.
S – DETECTING AND/OR RANGE AND BEARING, SEARCH.
T – TRANSMITTING.
W – AUTOMATIC FLIGHT OR REMOTE CONTROL.
X – IDENTIFICATION AND RECOGNITION.
Y – MULTI-FUNCTION.

[1] NOT FOR U.S. USE EXCEPT FOR ASSIGNING SUFFIX LETTERS TO PREVIOUSLY NOMENCLATURED ITEMS.