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DIRECTED ENERGY DEFENSES FOR COMMERCIAL AERODROMES TO COUNTER sUAS THREATS (PART 3)

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2019 ASSOCIATION OF OLD CROWS EW EUROPE CONFERENCE
STOCKHOLMSMÄSSAN, SWEDEN, 13-15 MAY 2019

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Virgin Atlantic jet carrying more than 260 people in NEAR-MISS with 2 drones near Heathrow

A VIRGIN ATLANTIC jet faced a collision at 14,000ft (4,267 metres) with two drones as it was approaching Heathrow Airport to land, sparking fresh fears over the dangers of remote-controlled aircrafts.

By ALICE SCARSI
PUBLISHED: 14:58, Sun, Apr 21, 2019 | UPDATED: 15:12, Sun, Apr 21, 2019

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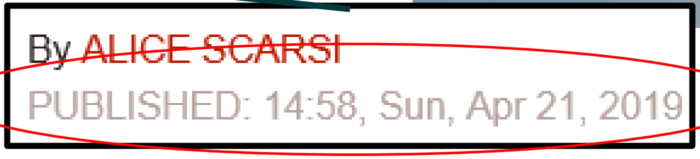
Note: Briefer rendition of incident; photo not taken of actual event



PROBLEM STATEMENT

The Problem of sUAS (a.k.a. Drones) Flying Dangerously Close to Airplanes and Airports is Rapidly Getting Worse

https://www.express.co.uk/news/uk/1117059/heathrow-airport-news-virgin-atlantic-jet-drone-law-new/

WHY ARE WE TALKING ABOUT SMALL UNMANNED AERIAL SYSTEMS (sUAS)?

- Weaponized sUAS are becoming commonplace on the battlefield
  - Military grade ordnance difficult to obtain, simple explosives are not
- Capabilities of COTS sUAS are advancing rapidly, and are easily customized
- Weaponized sUAS have already crossed into the civilian sector; Venezuelan President Assassination Attempt [2018] -LINK

Video compilation provided by Booz Allen Hamilton based on open source research

SMALL UNMANNED AIR SYSTEMS (sUAS)

- **U.S. Federal Aviation Administration (FAA) Guidelines:**
  - <55 lbs; including everything onboard/attached to the aircraft
  - Operated <100 miles per hour and <400 feet AGL
  - Typically operate under “See and Avoid” principles within “line of sight (LOS)”
- **FAA UAS regulatory evolution:**
  - Dec 2015 – FAA registration requirement for sUAS; >1,310,097 (Feb 1, 2019)
  - Aug 2016 – FAA/107 requires sUAS Remote Pilot Certificate (RPC) and daylight LOS; >119,837 RPCs issued and >2,335 Part 107 waivers issued for non-airspace and/or nighttime operations
  - Jan 2019 - U.S. DOT proposed new rules and pilot project to allow sUAS to fly at night/over people without waivers to integrate them safely into the NAS
  - Feb 2019 - Small drone owners to display registration on external surface of the aircraft

National Intent Towards Integrating sUAS into Airspace

https://www.icao.int/APAC/Meetings/2019%20APUASTF3/IP06%20Update%20on%20the%20FAA's%20UAS%20Integration%20Efforts.pdf#search=small%20uas;

RECAP OF 2017 & 2018 AOC EW EUROPE CONFERENCE BRIEFINGS

2017: DE Capabilities Provide Engagement Options for Short Timelines and UAS Threat Evolution

- Ubiquitous nature of sUAS and rising danger of their operation in the vicinity of commercial airports
- Defined the aerodrome operating environment and susceptibility of arriving & departing aircraft
- Discussed status of regulations and what happens when they fail
- Described a coordinated EW/DEW-Find/Fix/Track/Target/Engage/Asses (F2T2EA) Kill-Chain for sUAS
- Described a need for C2, visualization, training, and tactical decision aids to address short engagement timelines and evolution of sUAS threats that may challenge EW

2018: DEW lethality can be predicted and collateral damage can be managed; allowing safe and effective employment of DEW counter-sUAS capabilities

- Multiple sUAS collisions with aircraft reported since the 2017 AOC brief (none previously confirmed)
- Adversaries will seek to create a "shock & awe" event inside aerodrome operating environment
- Aerodromes present complex defense scenario; active defenses require collateral damage mitigation
- DEW offer a robust, cost-effective, and sustainable response to many of today's challenging threats
- DEW lethality is target specific; decision aids improve operational viability; training, integration, and situational awareness improve operational effectiveness and reduce collateral damage concerns

sUAS OPERATIONS IN VICINITY OF AERODROMES

https://www.digitaltrends.com/cool-tech/drone-plane-encounters/

AIRLINERS/AIRPORTS HAVE LONG BEEN A TARGET OF TERRORISTS ATTACKS


News › World › Africa

Isis plane attack: Egypt admits 'terrorists' downed Russian Metrojet flight from Sharm el-Sheikh for first time

Officials had previously denied Isis claims of responsibility and an Egyptian report claimed there was no evidence of 'terrorist action' in December

Lizzie Dearden | @lizziedearden | Wednesday 24 February 2016 14:27 GMT | 4 comments

134 shares

Like Click to follow

Russian Emergency Situations Minister Vladimir Puchkov (4-L) and unidentified officials near a piece of wreckage of Russian MetroJet Airbus A321 at the site of the crash in Sinai, Egypt EPA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Securing airports from attacks: Is it mission impossible?

By Richard Westcott
Transport correspondent, BBC News

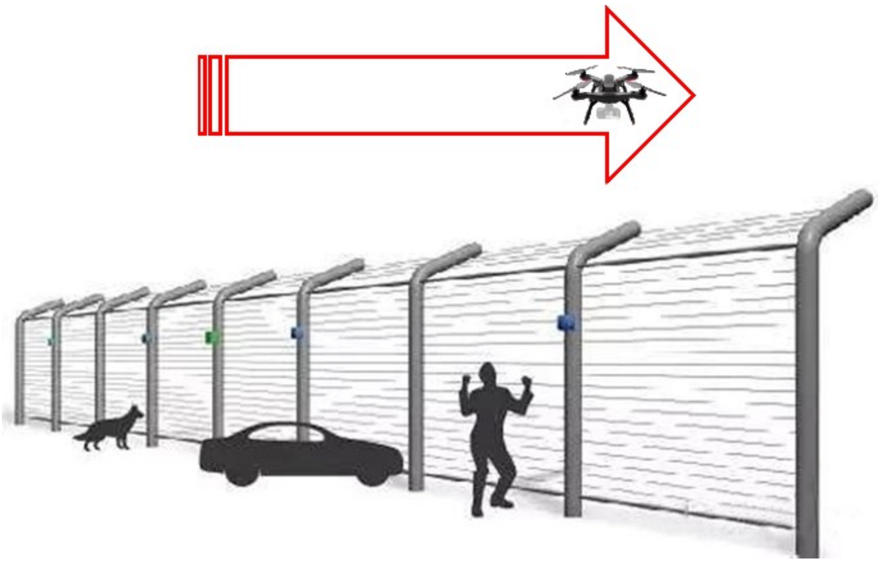
29 June 2016 | Europe

Share

AP

Turkey's Ataturk airport is a major transportation hub

"What has changed in recent years is the suicide element. That's difficult to counter, if people are willing to blow themselves up".



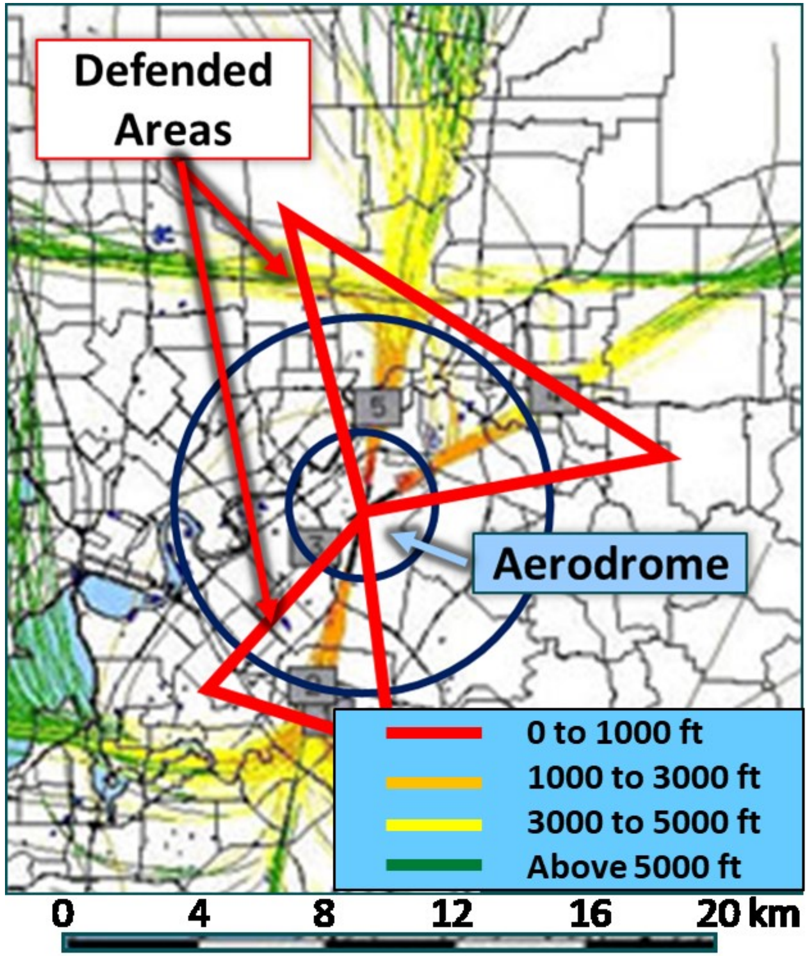
- Terrorists are inclined to attack airports because of their symbolism as an international hub with many international travelers, internal security check points, and large economic impact
- Psychological return of an airport/aircraft attack amplifies previous incidents, shakes confidence
- Fact: Every counter-terrorism move results in a counter-move to defeat security

sUAS (or Drones) have the ability to bypass all existing physical security measures

http://esnews.bah.com/small-commercial-unmanned-air-systems-an-amazing-technological-advancement-and-a-growing-threat-to-civilians-and-military-operations/#more-375;
http://www.zxairports.com/en/index.php?id=13

OPERATIONAL ENVIRONMENT

- Takeoffs/landings are the most critical portions of flight due to low speed/altitude
- Aerodromes have standard departure/arrival routes for noise abatement and runway alignment
  - Highly restricted and predictable paths enabling straightforward targeting from bad actors
    - Slight silver lining in detect-to-engage: restricted corridors dictate smaller defended area (in red), help placement of detection and engagement systems
  - Departure graphic at right shows:
    - Roughly 2-3 km (~45 seconds) from runway center to climb through 1000 ft AGL
    - Roughly 6-8 km (~2 minutes) to 3000 ft AGL

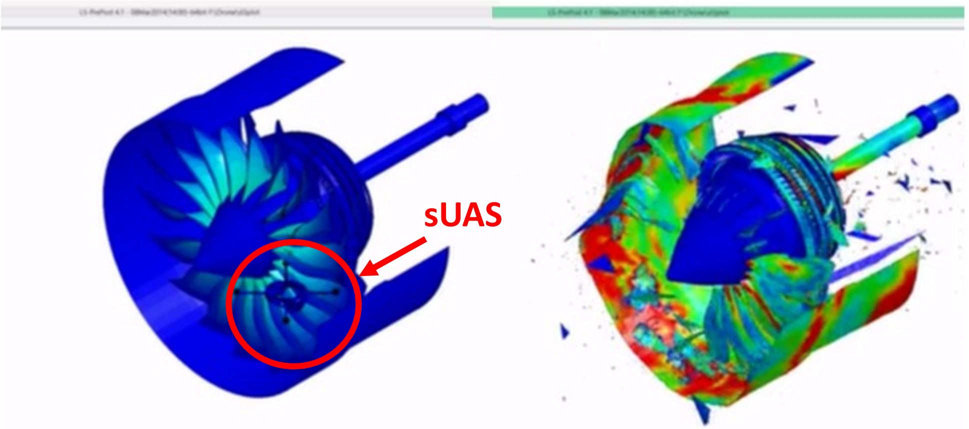


Aerodrome Environment Presents Numerous Cooperative Airborne Targets in Predictable Engagement Windows

http://aspm.faa.gov/opsnet/sys/opsnet-server-x.asp
http://www.airservicesaustralia.com/western-australia-route-review-project-warrp/information-for-the-community/

POTENTIAL CONSEQUENCES OF sUAS-AIRCRAFT COLLISION

Crashworthiness for Aerospace Structures and Hybrids (CRASH) Lab at Virginia Tech (sUAS Hits Engine)



http://www.popularmechanics.com/flight/drones/a24467/drone-plane-collision/

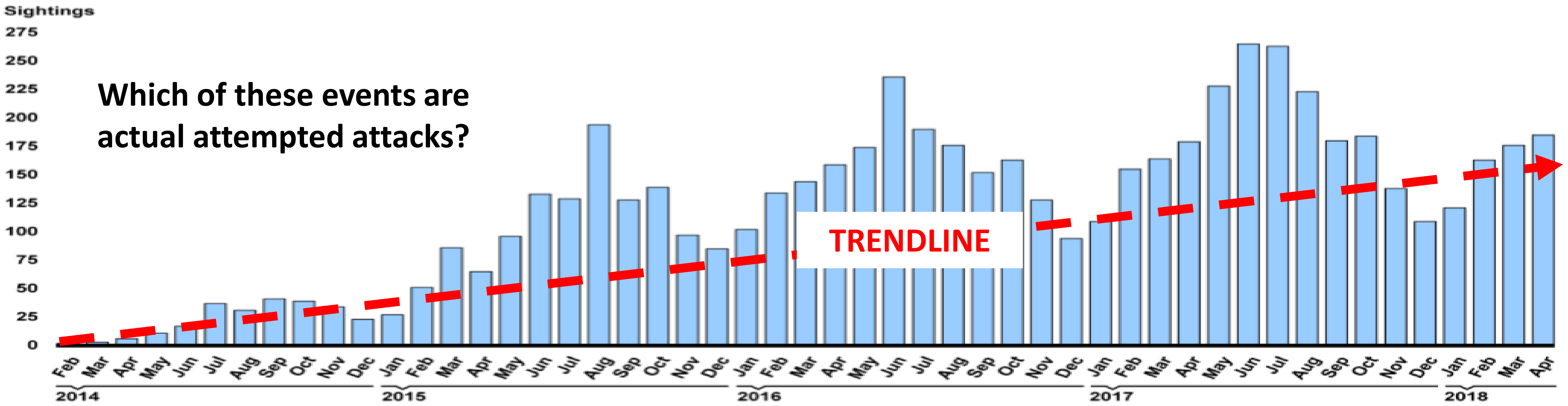
- Accidental bird strikes have long been a problem, have caused considerable damage (i.e., viscous fluid)
- Virginia Polytechnic Institute and State University ("VA Tech") researchers have begun analyzing consequences of sUAS collisions with commercial airliners:
  - 8-pound quadcopter can rip apart fan blades of a 9-foot diameter turbofan engine in less than 1/200th sec
  - Drone battery is much less compressible
- University of Dayton Research Institute's Impact Physics Lab simulated the damage caused by a drone involved in a high-speed collision with an aircraft wing (238 mph)

Due to Damage a sUAS can Inflict on a Passenger Aircraft, Pilots have Made Evasive Maneuvers

http://www.vtnews.vt.edu/articles/2015/10/102815-engineering-jetenginedronestrike.html
https://www.bing.com/videos/search?q=university+of+dayton+research+institute+drone+hits+airliner&&view=detail&mid=FC43A1BF7E4FE446ED1EFC43A1BF7E4FE446ED1E&&FORM=VRDGAR

COMFORTABLY, UNCOMFORTABLE

- **Feb 2014 - Apr 2018:** 6,117 pilot reports of sUAS sightings around airports or airborne manned aircraft



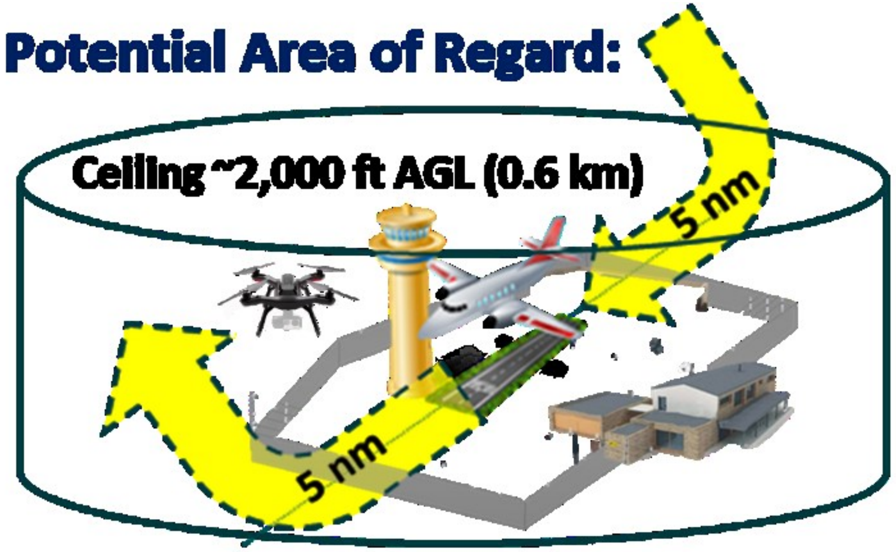
- **Dec 2018 – Present:** Airports in various cities — including Newark, New Jersey; Gatwick, England; Dublin, Ireland and Dubai — have grounded planes following drone sightings. London's Gatwick Airport event disrupted 1,000 flights and the plans of 140,000 passengers

- sUAS operations present increasing risks to airfield operations; whether through enthusiasm, ignorance, or malicious intent

Are we allowing adversaries multiple attacks today because sUAS are "unarmed"?

https://www.gao.gov/assets/700/692010.pdf; 2. https://dronedj.com/2018/04/12/the-international-civil-aviation-organization-calls-for-drone-airspace-management-solutions/; https://kbzk.com/news/2019/03/05/airports-scramble-to-handle-drone-incidents/; https://dronelife.com/2019/04/18/airport-execs-want-the-authority-to-protect-their-communities-from-drones-now-the-faa-wants-them-to-know-they-have-the-authority-kind-of/

DEMONSTRATED AERODROME SUSCEPTIBILITY



Israel | IDF & Security | Global | UK | News & Views | Terrorism | Science and Tech

UK Army Used Rafael 'Drone Dome' to Beat Gatwick Drone

By **David Israel** - 15 Tevet 5779 – December 23, 2018 0

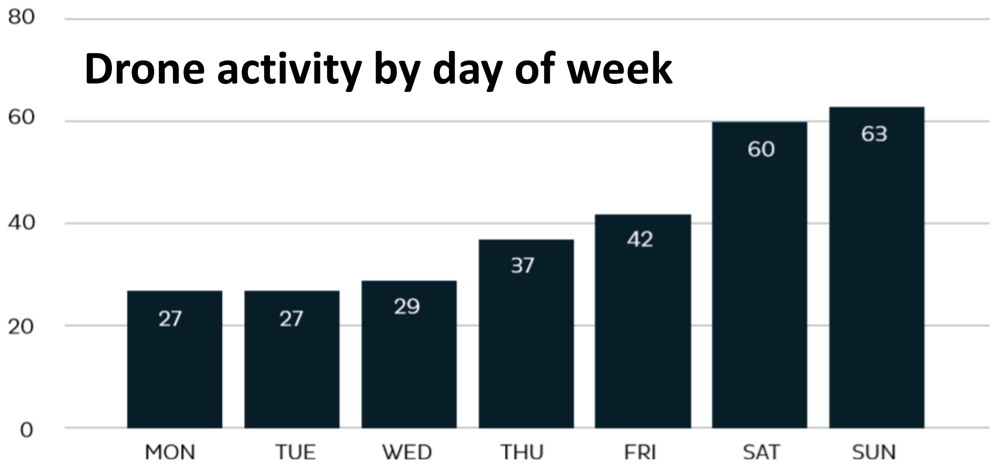
- Conventional EW systems being considered for airport defense

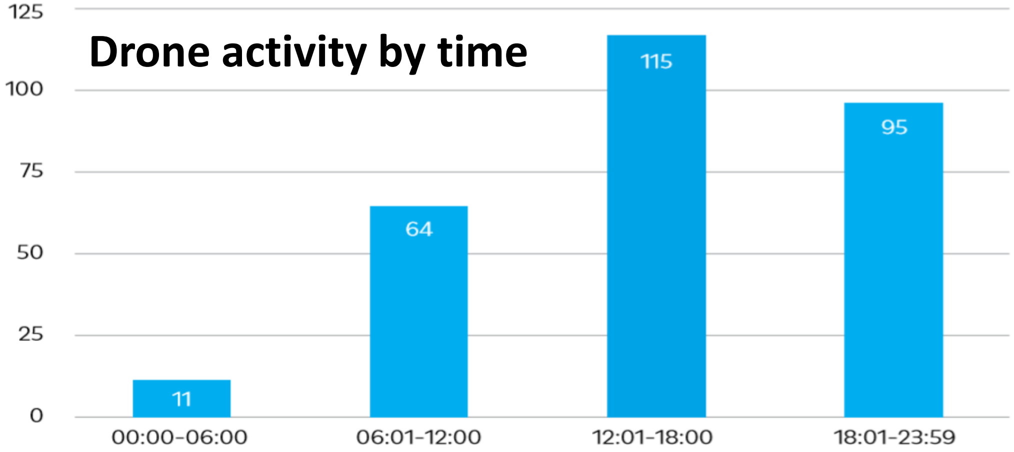
Threat mitigation activities are just beginning to appreciate airborne vectors

http://dronecenter.bard.edu/files/2015/12/12-11-Drone-Sightings-and-Close-Encounters.pdf; https://www.dailymail.co.uk/news/article-6518503/How-Australian-company-solve-Gatwick-Airports-drone-crisis.html
https://www.jewishpress.com/news/global/uk/uk-army-used-rafael-drone-dome-to-beat-gatwick-drone/2018/12/23/

IS THERE REALLY AN ISSUE?

- 2018, Dedrone® installed **detection** technology at 4 airports in the UK to measure incursions
- 285 drones detected in 148 days; key finding:
  - Problem is real, not anecdotal: Drones disrupted UK airports causing loss of revenue due to closed runways
  - Drone pilots fly a broad spectrum of technology from different manufacturers, and detection technology must be able to capture all drone activity
  - UK drone pilots come out to fly at airports around the same time and days

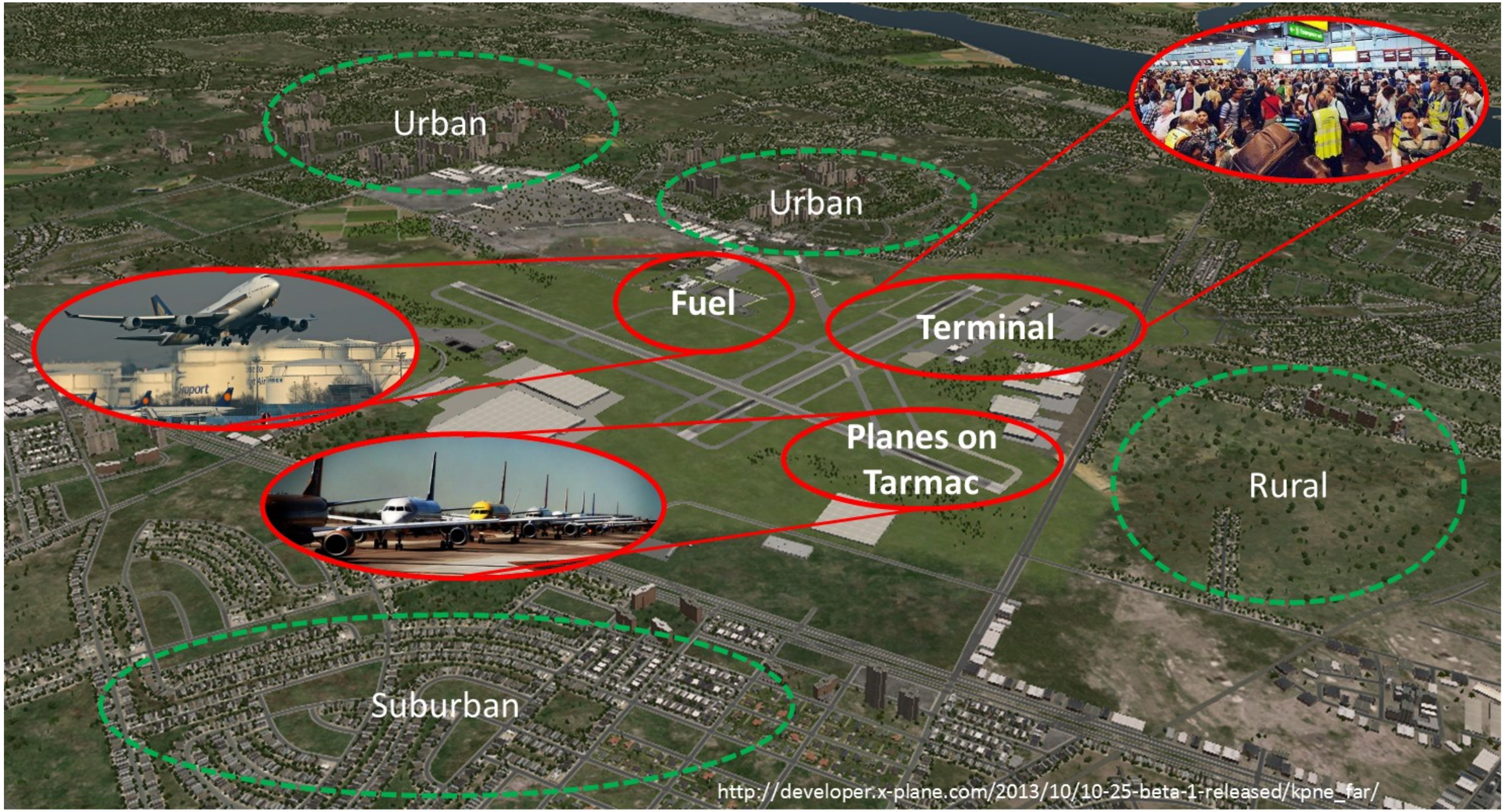




Directed Energy Technologies can Help Mitigate Potentially Catastrophic Collisions

https://www.dedrone.com/lp/airport-airspace-report

INTERNATIONAL AIRPORTS PRESENT A COMPLEX ENVIRONMENT



Multiple Stationary Targets, in Addition to Aircraft on Approach or Taking Off

sUAS POSE A SIGNIFICANT GROWING ASYMMETRIC THREAT

Asymmetric War

ISIS drones dropping ordinance in Syria [2017] 1-LINK

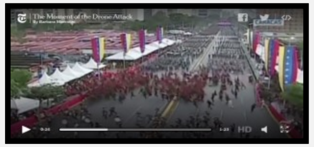
$3K Russian Drone w/ Thermite Grenade Detonated $1B of Ukrainian Ammunition [2017] 3-LINK

A swarm of 13 armed drones attacked a Russian military base in Syria [2018] 5-LINK

Heads of State Danger

Drone incidents with Heads of States show catastrophic impact potential of weaponized UAVs [2013] 2-LINK

U.S. Secret Service Arrests Man After Drone Flies Near White House [2015] 4-LINK



Venezuelan President Assassination Attempt [2018] 10-LINK

Terrorism

ISIS creates propaganda video envisioning drone strikes on 2018 World Cup Games [2018] 6-LINK

Domestic Threats

HH-60 and DJI Phantom 4 mid-air collision over NYC – Aircraft had Minor Damage [2017] 7-LINK

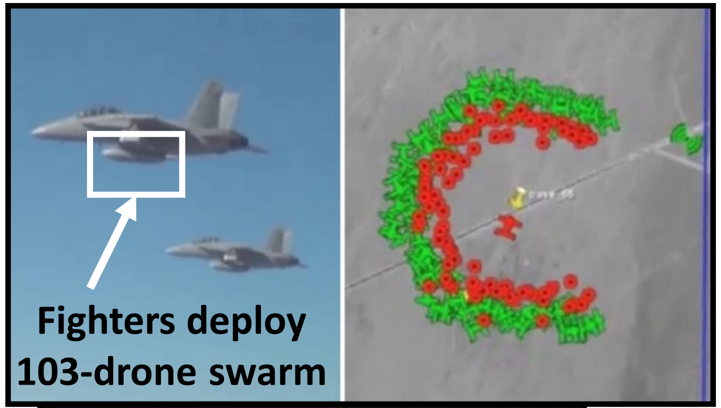
Close encounter drone w/ 737 in Las Vegas [2018] 9-LINK

95 non-permissive drone flights over a joint base in 56 days [2017] 8-LINK

Close encounter drone w/ helicopter in Miami [2018] 12-LINK

CONTINUING TECHNOLOGY DEVELOPMENTS

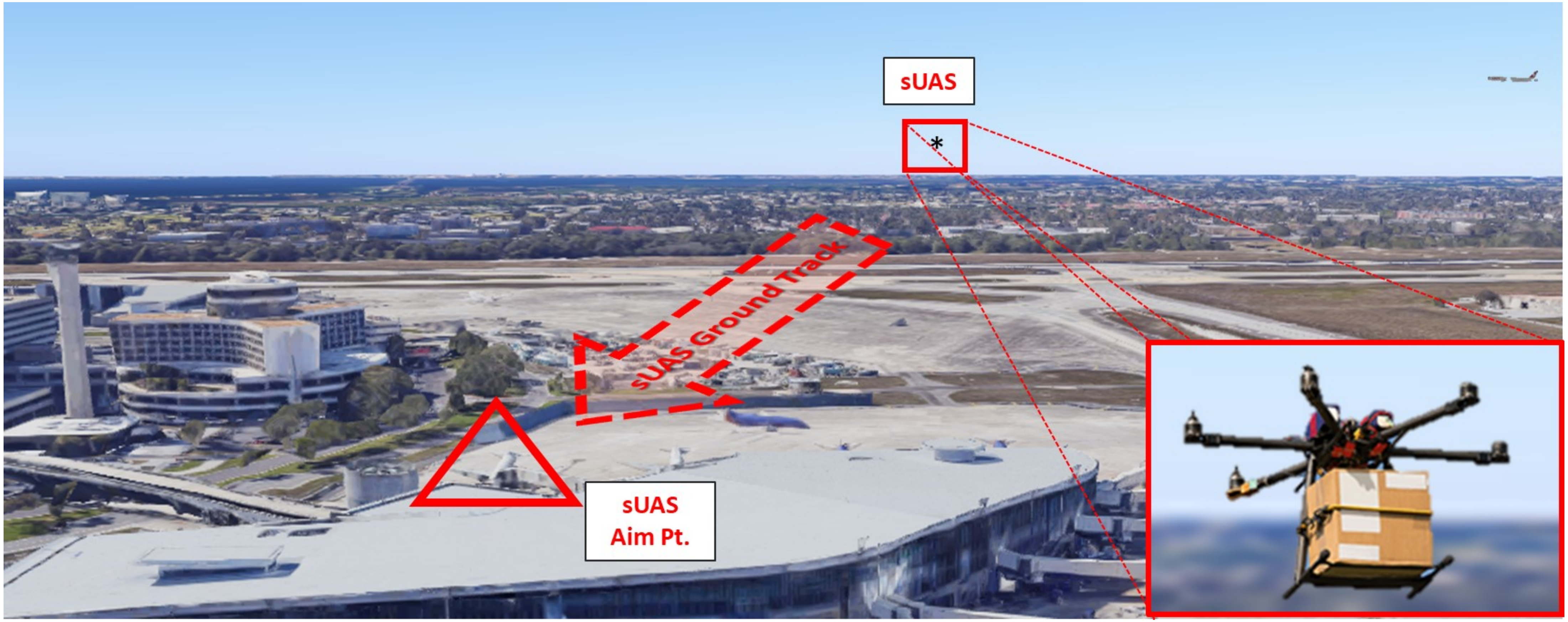
- **Intelligent "Drone SWARM" technologies**
  - **2016**: Intel able to control a 500-drone lightshow with one laptop
  - **2016**: Three F/A-18's launched 103 Perdix micro-UAV drone swarm
  - **2017**: A film produced by UC-Berkley and the Future of Life Institute, illustrating 'slaughterbots' with AI could be used to kill
  - **2018**: Intel controls 1,218 drones during Opening Ceremony of the Olympic Games in Pyeong Chang, South Korea
  - **2018**: 1374 synchronized drones at Labor Day Celebration in China
- "… drones will soon have a **hunt-and-destroy capability**. Algorithms exist today … with **"see-and-avoid"** ability as demonstrated at MIT ..."
  - Lt Col Leslie F. Hauck III, USAF, Dr. John P. Geis II, Colonel, USAF, (Ret), *Air Mines: Countering the Drone Threat to Aircraft*, Air & Space Power Journal, Vol. 31, No. 1, Spring 2017
- **Autonomy** and **Machine Learning**, takes away need for direct control
  - Potentially negates a significant EW attack vector



Imagine a World Where Terrorists Tactics Previously Discussed are Combined with these Technology Advancements

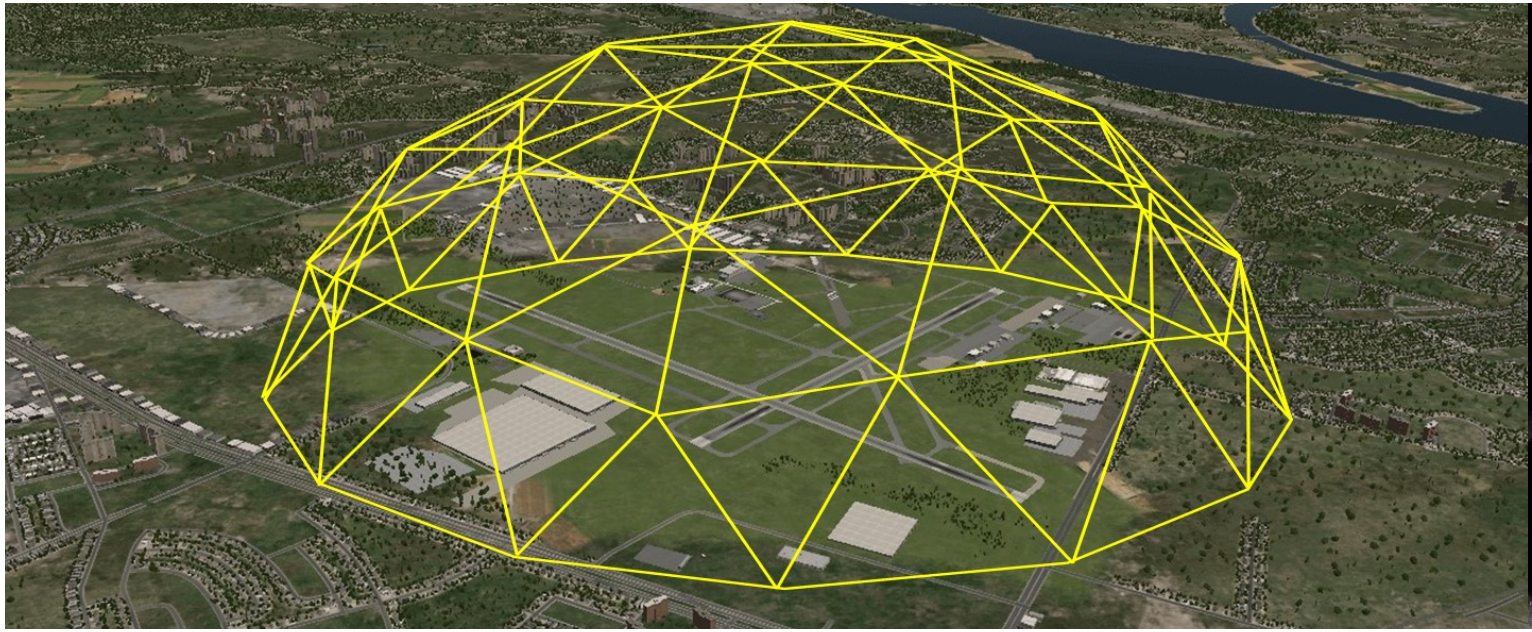
http://www.nextbigfuture.com/2017/02/oncoming-drone-swarms.html, http://www.foxnews.com/tech/2017/01/10/video-shows-fighter-jets-launch-swarm-tiny-drones.html
https://dronecenter.bard.edu/weekly-roundup-5-7-18/
http://thedronegirl.com/2018/02/11/olympics-intel-drone-light-show/; https://www.mirror.co.uk/news/uk-news/how-slaughterbots-could-become-terrifying-12041155

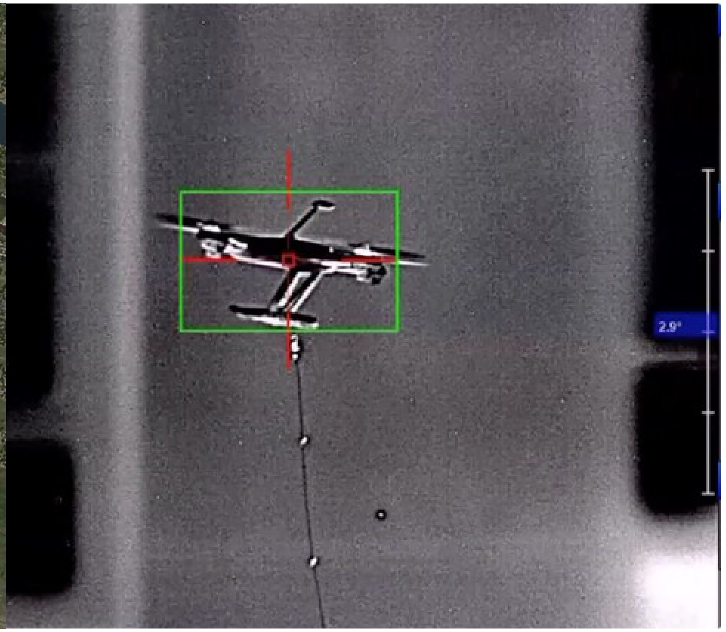
POTENTIAL TO TARGET AIRCRAFT ON RAMP



"Son still on tarmac 2am at Birmingham Airport after being diverted there at 10pm from Gatwick with no tangible update of what is to happen. Shambles."

https://www.birminghammail.co.uk/news/midlands-news/gatwick-drone-birmingham-diversion-stranded-15575958





COUNTERING sUAS

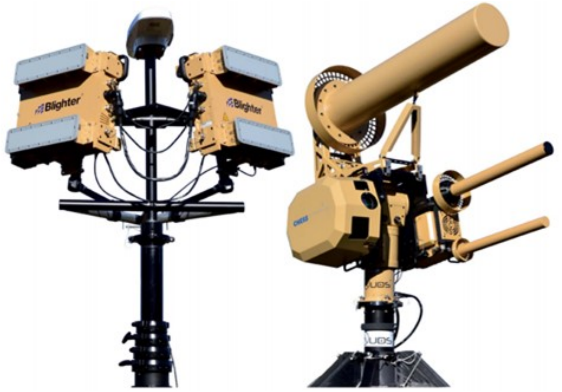
“Victory smiles upon those who anticipate the changes in the character of war, not upon those that adapt themselves after the changes occur.”

- Air Marshal Giulio Douhet, Command of the Air, 30, 1921

http://www.simulyze.com/blog/humanitarian-aid-gets-helping-hand-from-uas-technology

CONVENTIONAL-ELECTRONIC ATTACK (CONV-EA) UAS COUNTERS

- **Conv-EA approach to C-UAS:**
  - **Asymmetric target set** – will likely mirror counter-IED lifecycles
    - Adversary –technology access (buy/build); system reprogramming; TTP
    - Friendly – intelligence (human intelligence/forensics); EW system reprogramming; TTP
  - **Current EW approaches** deny, degrade, or deceive communication channels
  - **Broadband versus narrowband jamming:**
    - Broadband potentially – reduced effectiveness due to power-sharing; causes interference in friendly spectrum; increases effectiveness in multi-threat scenario (swarming UAS or multi channel C2)
    - Narrowband – highly dependent on predictable adversary or up-to-date intelligence; potential to miss target entirely; potential reduced effectiveness in multi-threat scenario
  - **Potential collateral damage or close EW attack vectors:**
    - Adversary can piggy-back comms on critical "local" networks (emergency response, GPS), or incorporate autonomy/waypoints capabilities



Primary Goal of EW is to Prevent the Successful Reception or Transmission of Data

Sandia National Laboratories, "UAS Detection, Classification, and Neutralization: Market Survey 2015; http://www.blighter.com/products/auds-anti-uav-defence-system.html, https://www.droneshield.com/dronegun

CONVENTIONAL-EA VECTORS TO COUNTER UAS (ALL GROUPS)

- Future developments in autonomy, artificial intelligence (AI), machine learning etc. will be problematic for EW

Platform

Payloads

Platform may include:

Airframe
Flight Controls
Communications (Tx & Rx)
Navigation
Critical Platform Subcomponents

- Attitude/Heading/Reference Systems
- Radar Altimeter (Tx & Rx)
- Autopilot

Propulsion

Payloads may include:

Communications (Tx & Rx)
Sensors (EO/IR, RF)
Weapons (Energetics, Sensors, Fuses)

Legend: Green Text Indicates Attack Vector

Threat Evolution Will Require More than Conventional-EA Techniques

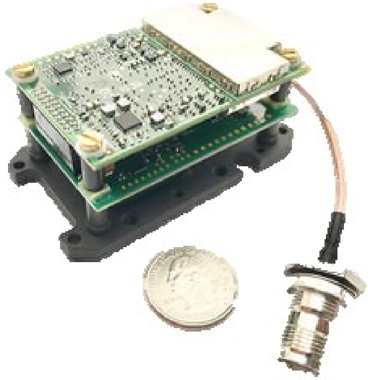
https://www.gpsworld.com/retailers-airspace-undetectable-drones-uav-developments-zoom-ahead/

UAS CONVENTIONAL ELECTRONIC ATTACK VECTORS

Category	Attack Vector	Conv.-EA Accessibility	Threat Evolution
Platform	Airframe	No	Materials, Stealth, Signature Contro
	Flight Controls	No	Materials, Housing, Flight Control Computers
	Communications	Yes (Rx)	Encryption, RF selectivity, Waveform Directionality, Autonomy
	Navigation	Yes (Rx)	Multi-modal, Anti-jam, Encryption, Directionality, Autonomy, M-code GF
	Critical Platform Subcomponents	No / Yes (Rx)	Materials, Housing, OPSEC
	Propulsion	No	Materials, Housing, OPSEC
Payload	Communications	Yes (Rx)	Encryption, RF selectivity, Waveform, Directionality, Nulling, Autonomy
	Sensors	Yes (Rx)	Multi-modal, Directionality, Nulling
	Weapons	No	Materials, Internal carriage

Threat Evolution Exemplars

GPS-INS



UAS SAR

Integrated GPS Anti-Jam System (IGAS)

Conformal Antennas

What Happens When Conventional EA Vectors Close?

https://www.c4isrnet.com/unmanned/2018/03/26/raytheon-darpa-developing-technology-to-control-drone-swarms/; https://inertiallabs.com/ins.html; http://censintechnology.com/Pharad-UAV-Antennas/; https://www.gpsworld.com/anti-jam-systems-which-one-works-for-you/; https://www.gpsworld.com/; http://www.barnardmicrosystems.com/UAV/features/synthetic_aperture_radar.html




DIRECTED ENERGY WEAPONS

Directed Energy Weapons Bring Promise

Graphics used with permission from Dr. Christopher Lloyd and Mr. Bryan Knott, NSWC Dahlgren, HEL Lethality Group

WHY DIRECTED ENERGY

- Threats for which kinetic or EW solutions are not sufficient
- DE technology has matured with sufficient SWaP-C to be integrated into platforms and address evolving threats
- ***Counter-Materiel*** applications have a wide range of potential uses to disrupt, disable, or destroy threat systems
- ***Counter-Personnel*** applications are effective
- DE weapons, like other weapons, could result in collateral damage and unintended harmful effects, which must be factored into guidelines regarding use

DE Weapons (DEW) offer a robust, cost-effective, and sustainable response to many of today's challenging threats

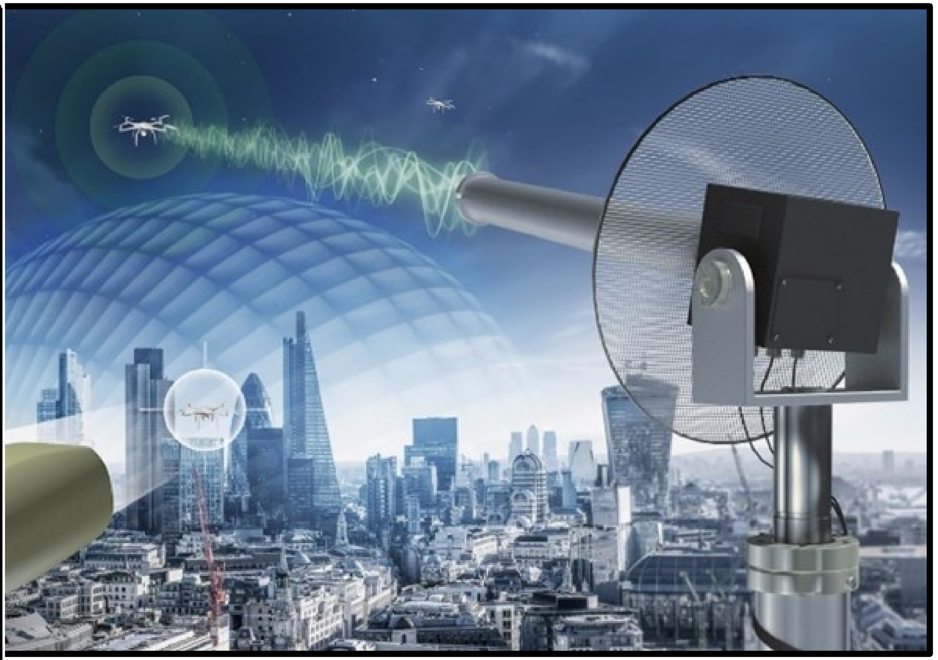
https://startwithwhy.com/

DIRECTED ENERGY

- **Definition:** Technology and weapon systems based on the application of force on target with electromagnetic energy vice Kinetic Energy (KE) (**no projectile**)

- **Advantages**
  - –Speed of light delivery
  - –Precise engagement
  - –Graduated effects
  - –Depth of magazine
  - –Low engagement cost

- **Energy Classes**
  - –High Energy Laser (HEL)
  - –High Power Microwave/Radio Frequency (HPM/HPRF)
  - –Charged/Neutral Particle Beams (not discussed here)



HIGH-POWER MICROWAVE/RF DISCUSSION

"I never worry about action, but only about inaction."

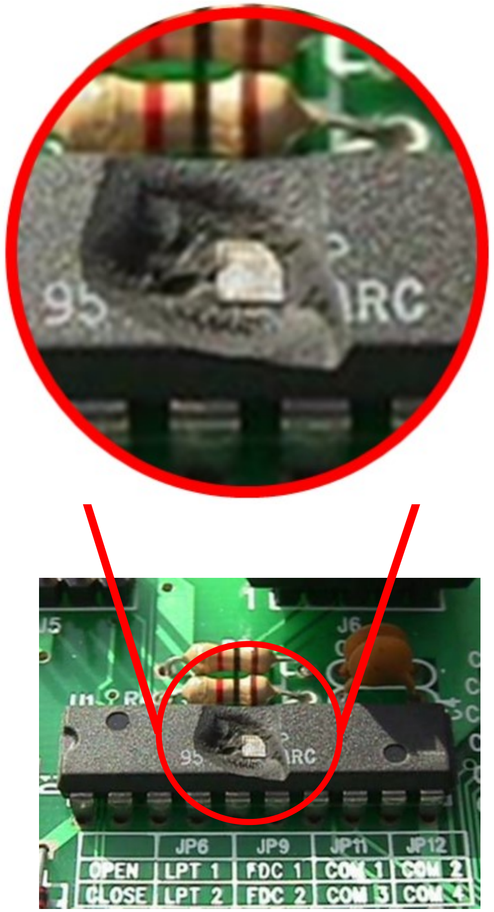
- Sir Winston Churchill

https://www.wired.com/2009/04/pain-beam-secre/
https://www.wpafb.af.mil/News/Photos/igphoto/2000329975/
http://smalldronesreview.com/2016/02/08/top-list-of-anti-drone-weapons-drone-killers/

HOW HPM/HPRF ENERGY AFFECTS TARGETS

- **Electromagnetic Interference (EMI):** is the disruption of an electronic device when it is irradiated by an EM field in the RF spectrum
- **How?** RF energy couples into circuits resulting in transient voltages being created within the electronic device that can **disrupt** its operation, or can even be greater than their limits (several Volts), causing breakdown or arcing within the chips (i.e. **damage**)
- **Energized circuits** often require very little energy to initiate a catastrophic device failure – with most energy supplied by the power supply
- **Sources of EMI:** lightning, power lines, leaky microwave ovens, radio towers, cell phones, radars, Wi-Fi, Bluetooth, wireless, etc.

Can Result In →

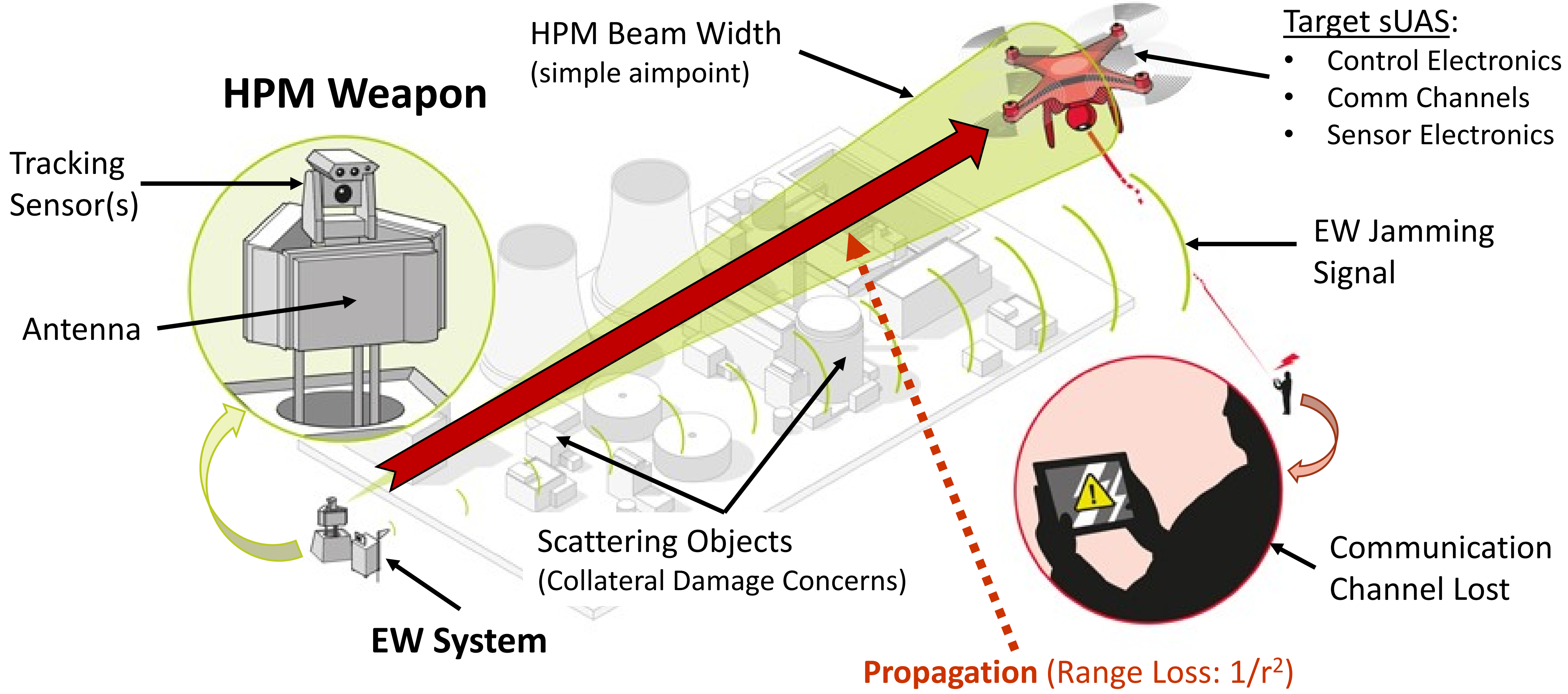


Intentional EMI: Intentional generation of EM energy to introduce noise or signals into electronic systems, thus disrupting, confusing or damaging these systems for military, terrorist, or criminal purposes[1]

[1] URSI XXVIth General Assembly in Toronto, August 1999

HPM WEAPON CONCEPT: *INTENTIONAL EMI*

- Coupling between the weapon and targets influenced by **range** and **scattering**
- **Target susceptibility data required** to determine vulnerability to attack



http://smalldronesreview.com/2016/02/08/top-list-of-anti-drone-weapons-drone-killers/

DIRECTED ENERGY (HPM/HPRF) LETHALITY

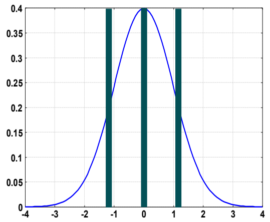
- In principal, **ALL electronic devices can be disrupted or damaged by RF energy**; the key is whether or not it <u>can be *operationally exploited*</u>
  - **HPM Weaponeer** must identify appropriate targets (sUAS & controllers), identify desired kill mechanisms and outcomes, and field an operationally viable weapon that achieves those objectives
  - **sUAS Operator** must identify own weak points and defend them against realistic attack scenarios (risk vs. cost trades); much more difficult than you might think

Low-cost surrogates support the development of HPM/HPRF target probability of effect (P_e) curves

http://www.militaryaerospace.com/articles/print/volume-27/issue-11/special-report/the-dawn-of-counter-drone-technologies.html

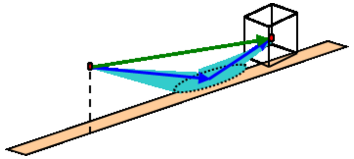
HPM ENGAGEMENT LETHALITY M&S: SOURCE-TO-TARGET MODELING

HPM SYSTEM



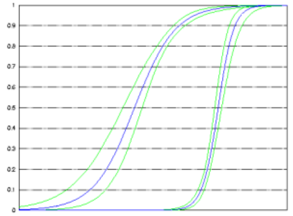
- Parametric Model
- Data Tables
- Analytic Parametric Models (state-of-the-art laboratory systems)
- Point designs

PROPAGATION MODELS



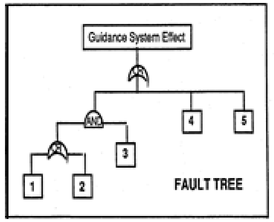
- Exterior & Interior
  - Ray-tracing (e.g., RF-PROTEC, Wireless InSite)
  - FDTD/NEC validations
  - Terrain modeling

PROBABILITY OF EFFECT (P_e) MODELS



- One-dimensional and multidimensional P_e curves/surfaces from experiments, using “design of experiments” methodology

PROBABILITY OF KILL (P_k) MODELS



- FALT/Target Models (e.g., JREM)
- Advanced network analysis/models (e.g., OPNET)

MISSION AND CAMPAIGN-LEVEL ANALYSIS

- Mission (e.g., EADSIM, SUPPRESSOR)
- Campaign (e.g., THUNDER, CFAM)

While weather impacts are minimal for HPM weapons, HPM effects are statistical in nature and require extensive testing and analysis to determine effectiveness

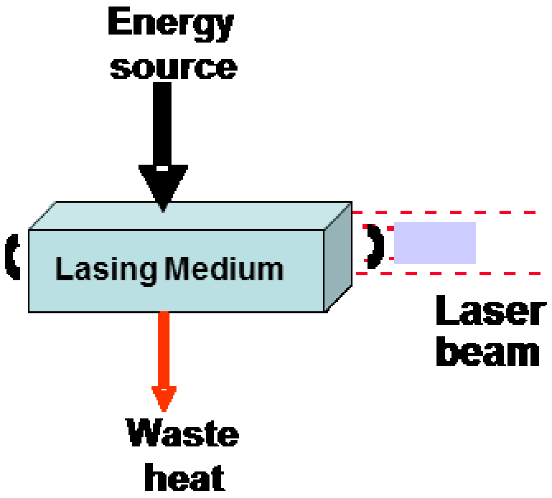
http://www.militaryaerospace.com/articles/print/volume-27/issue-11/special-report/the-dawn-of-counter-drone-technologies.html

HIGH-ENERGY LASER DISCUSSION

https://www.businessinsider.com/soldiers-testing-the-armys-new-laser-weapon-to-shoot-down-drones-2018-3 ; https://breakingdefense.com/2018/03/first-combat-laser-for-navy-warship-lockheed-helios/
http://www.airforcemag.com/Features/Pages/2017/November%202017/Lasers-Coming-to-USAF-Fighter-Jets-By-2021.aspx ; https://www.businessinsider.com/laser-drone-missile-defense-boost-phase-intercept-2017-6

BASIC ELECTRIC LASER WEAPON ATTRIBUTES

- ***Begins*** **delivering energy to the target at the “speed of light”**
  - Ideal for long range targets or if quick reaction is needed
  - Insensitive to threat maneuvers
- **HEL places a focused spot of light (visible or IR) on a target**
  - Rapidly heats a small area on the target
  - Effect is similar to a “blowtorch”
- **Beam *dwell time* is required to cause damage**
  - Similar to a plumber’s torch soldering a copper-pipe joint
  - Heating rate determines target kill-time (energy deposited)
- **Uses electric power instead of bullets/projectiles**
  - About 1/3rd converts into the laser beam **(*~30% efficiency*)**
  - Remaining 2/3rd is waste heat (system design)



Irradiance measures the heat of the “blow-torch” beam

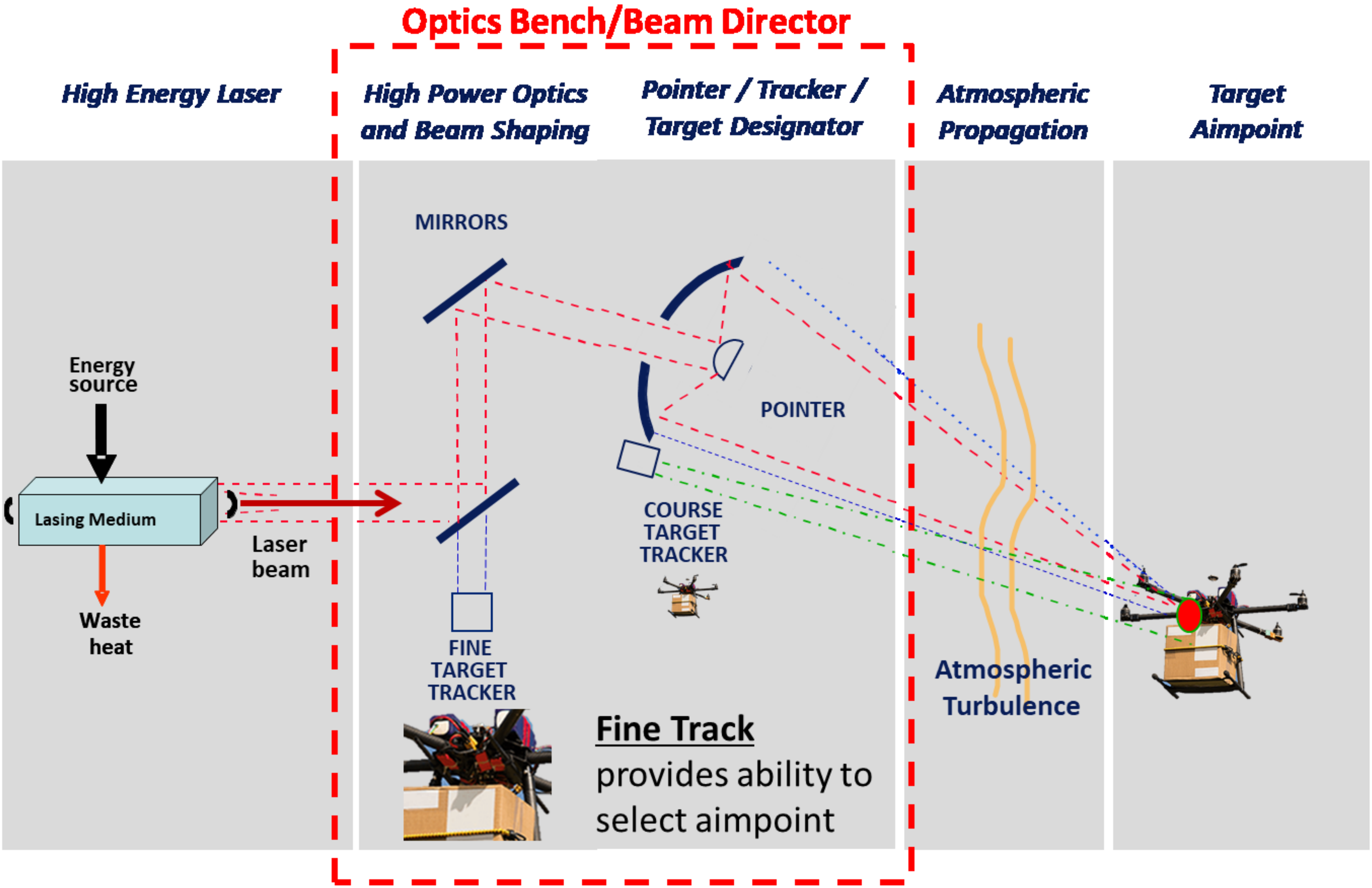
- Irradiance = power/spot area (Watts/cm^2)

Fluence measures the accumulated energy on the target

- Fluence = time x irradiance (Joules/cm^2)

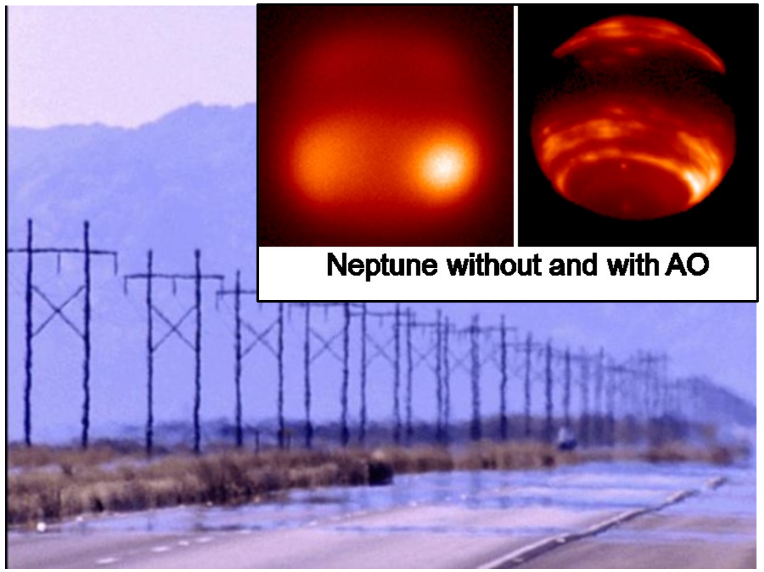
https://www.stripes.com/news/army-tests-drone-killing-lasers-as-threat-grows-on-the-battlefield-1.464368

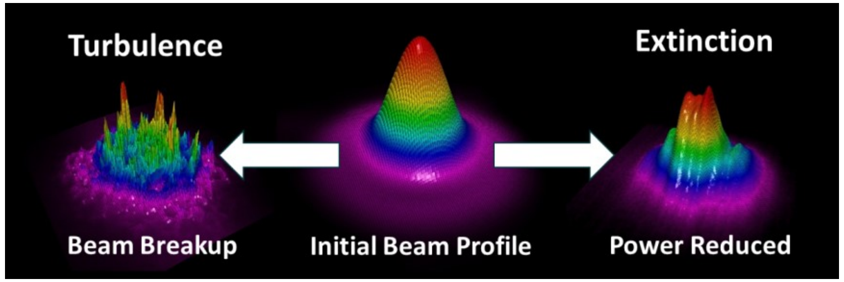
ELEMENTS OF A HEL WEAPON SYSTEM



WEATHER AND HEL PROPAGATION

- **Turbulence** caused by air/sea/ground temperature differences that create a movement of bubbles of hot air, affecting the propagation
  - Turbulence impacts the ability to focus to a tight spot
  - Can often be improved with Adaptive Optics (AO)
- **Extinction** is the scattering and absorption of laser energy
  - Elements/particles in air reflect, deflect, and absorb HEL energy and lower the irradiance at range
  - Water vapor and particles (clouds, fog, rain, smoke)
- **An HEL beam can heat its propagation path**
  - "**thermal blooming**" can impact an HEL weapon's ability to focus to a small spot (creates a negative lens effect)

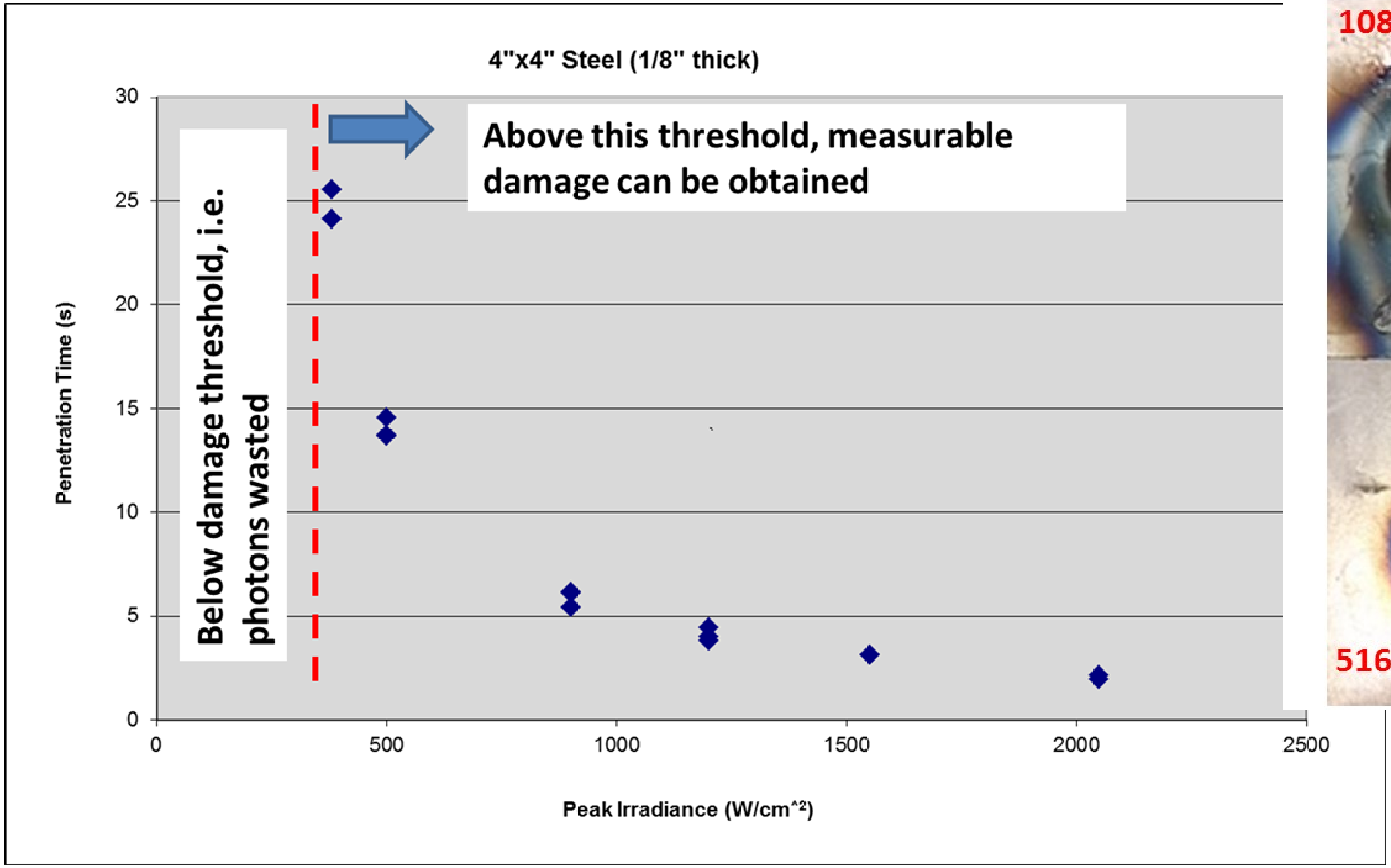


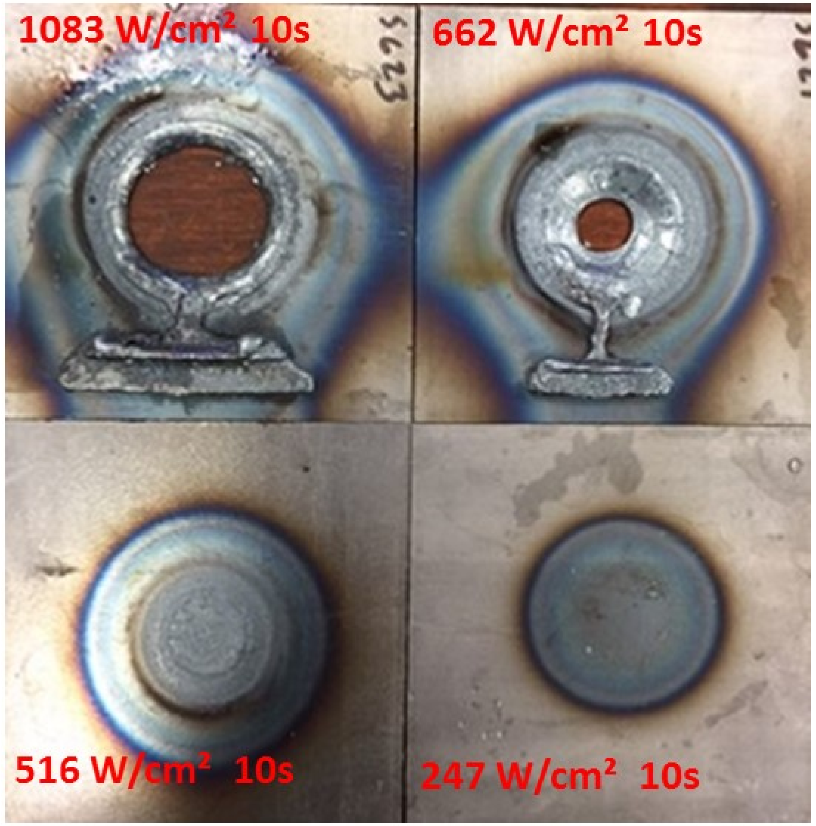


Propagation Knowledge Impacts/Reduces Safety Buffers

Claire Max, "Adaptive Optics and its Applications, Lecture 1," UC Santa Cruz January 12, 2016

4”x4”x1/8” STEEL: IRRADIANCE MELT-THROUGH CURVE





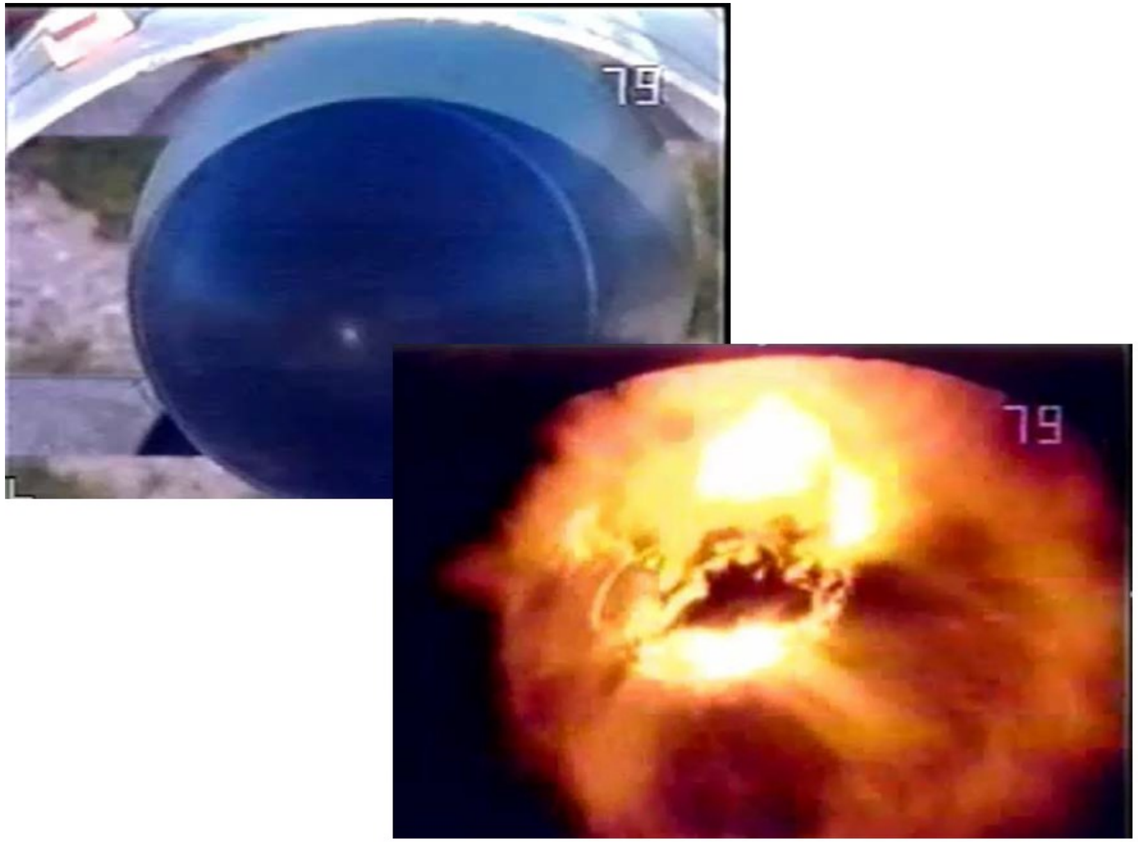
Penetration Times Are Highly Material Dependent

Graphics used with permission from NSWC Dahlgren, HEL Lethality Group

HIGH-ENERGY LASER MISSILE-LETHALITY TESTS

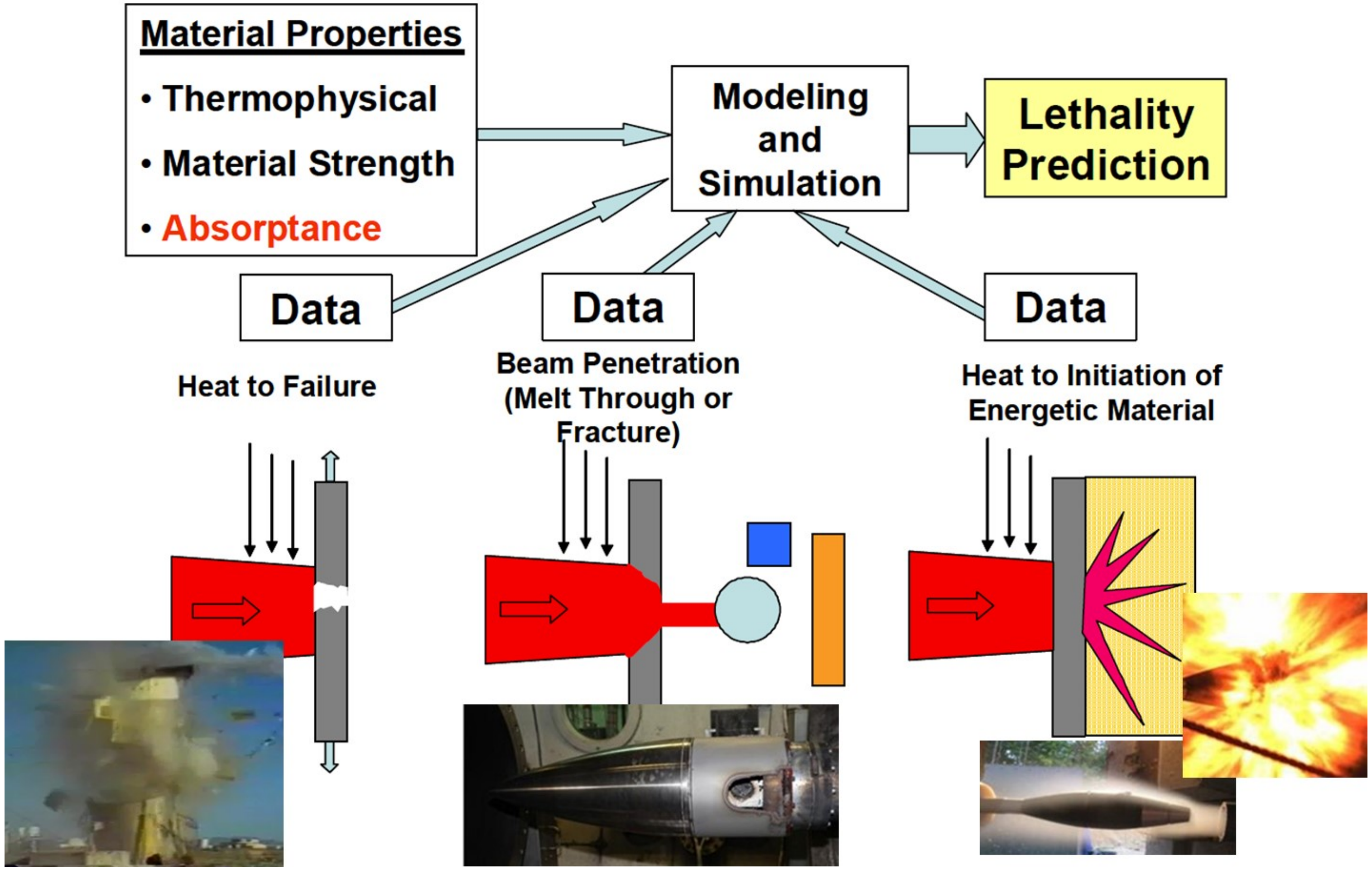
Actual Flight Aerodynamics
(On guiding wire)

Simulated Flight Aerodynamics
(Use of air flow)



http://www.miltechmag.com/2014/03/todays-directed-energy-weapons-meeting.html

PRIMARY TARGET KILL MECHANISMS LEADING TO LETHALITY PREDICTION



Pressurized Rocket Motor

Side-Shot Anti-Ship Missile

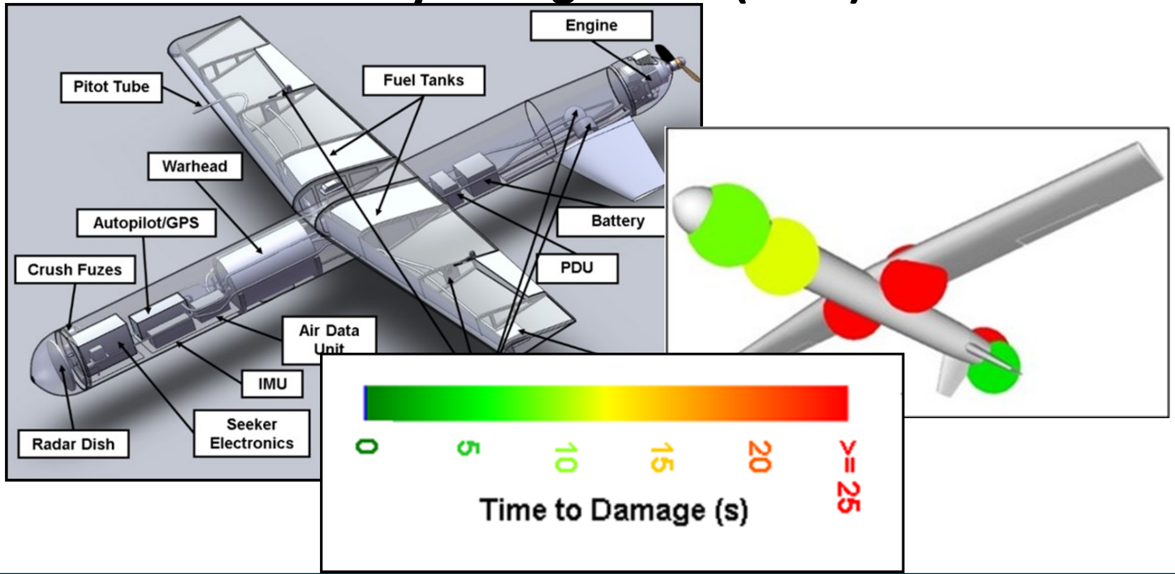
Deflagration of Mortar Round

Graphics used with permission from NSWC Dahlgren, HEL Lethality Group

HEL: TARGET VULNERABILITY CHARACTERIZATION

- Larger UAS targets require acquiring the target and analyzing its functions and sub systems
- **Failure Modes Effects Analysis (FMEA)** results in a target vulnerability characterization
  - Target geometry model
  - Component properties and damage criteria
  - **Failure Analysis Logic Tree (FALT)**

- sUAS Present a simplified target approach
- Targets readily available for acquisition and testing
- FMEA characterization
  - Component properties and damage criteria easily determined
  - FALT normally yields "center-of-mass" targeting



Results in HEL Aimpoints, Each with a Required Fluence for a Particular Damage Criteria

Graphic used with permission NSWC Dahlgren, HEL Lethality Group
https://www.army.mil/article/167447/HEL_MTT_fires_away_during_MFIX_2016

DIRECTED ENERGY (HEL) LETHALITY

- **Probability of Kill (P_k) is a function of:**
  - **Irradiance [W/cm2] on target**
  - **Target susceptibility = ƒ(fluence [J/cm2] on a particular aimpoint)**
  - **Engagement time (not instantaneous) = ƒ(irradiance, target susceptibility)**
- **P_k Estimation is Complicated by:**
  - **Propagation = ƒ(turbulence, extinction, thermal blooming, etc.)**
  - **Target aimpoint maintenance = ƒ(susceptibility, selection, aspect angle=ƒ(time))**
  - **Range = ƒ(time)**
  - **HEL system jitter, power, beam quality, etc.**
  - **Target kill mechanism**

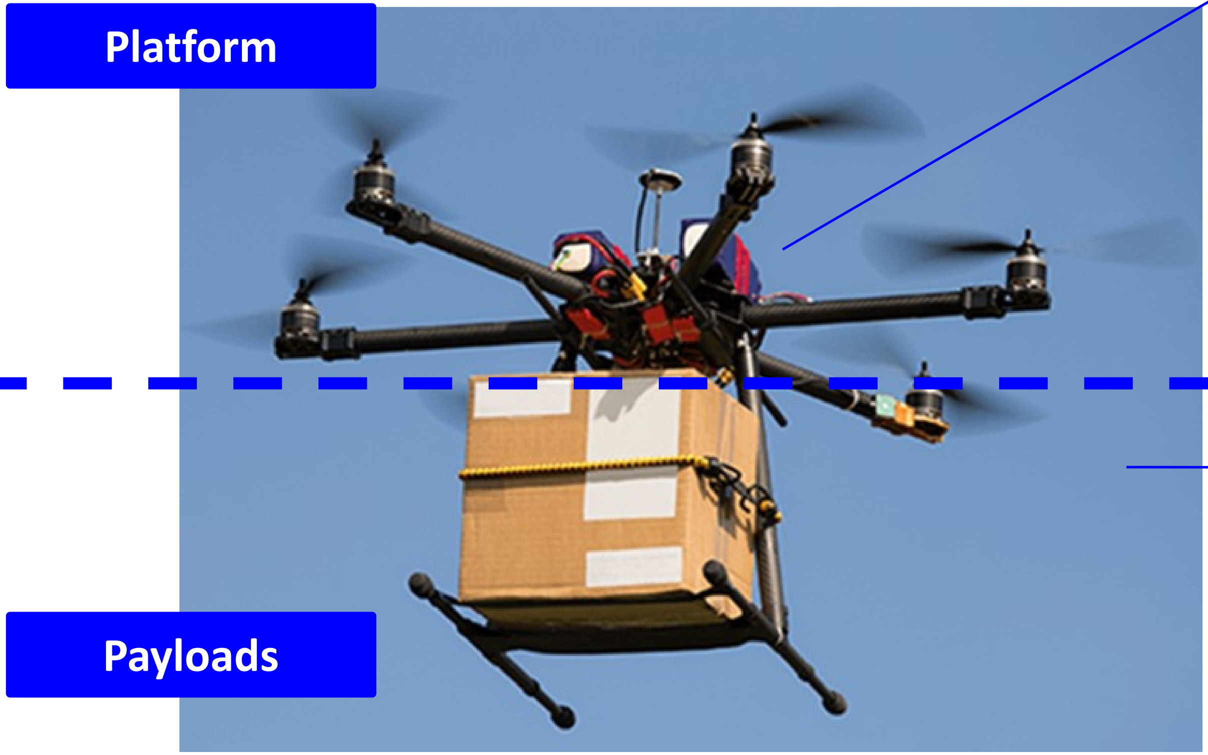
Battle Staffs Near Full Capacity {
Current Tasking
Battle Staffs
Support Infrastructure

http://1funny.com/brick-bicycle/

Tactical decision aids should address these factors to improve operational viability

ELECTROMAGNETIC-ATTACK VECTORS TO COUNTER UAS (ALL GROUPS)

- Combination of conventional-EA with DEW increases attack options and range of effects (deny, degrade, deceive, destroy)



Platform typically includes:
Airframe
Flight Controls
Communications (Tx & Rx)
Navigation
Critical Platform Subcomponents
Propulsion

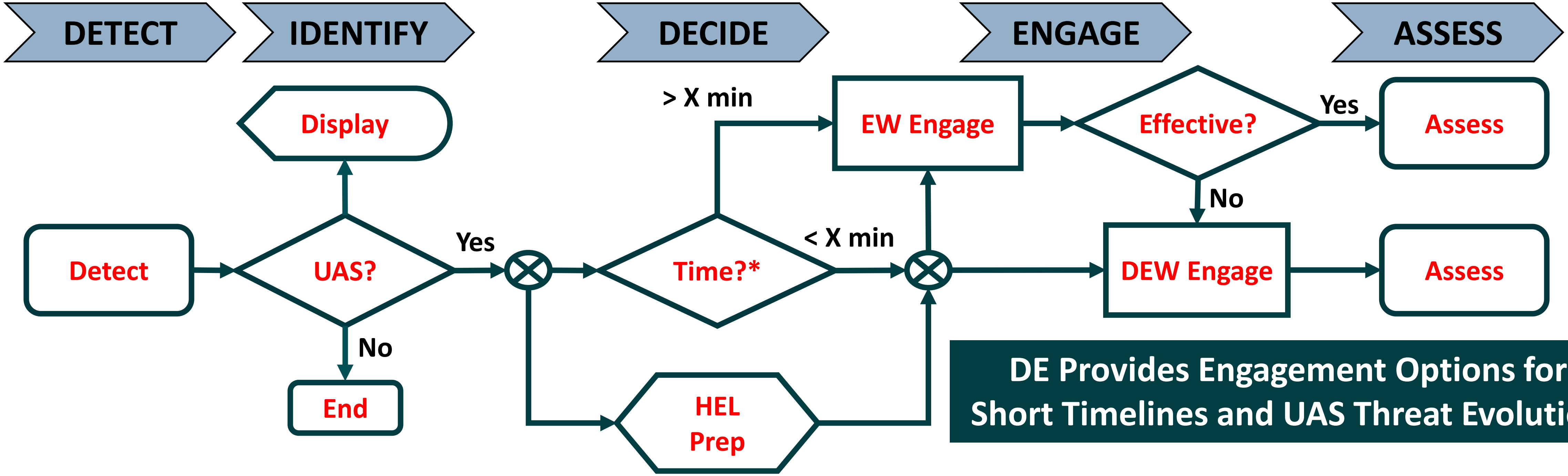
Payloads typically include:
Communications (Tx & Rx)
Sensors (EO/IR, RF)
Weapons (Energetics, Sensors, Fuses)

Legend: Green Text Indicates Attack Vector

Electromagnetic Attack Provides a Robust C-UAS Capability

https://upload.wikimedia.org/wikipedia/commons/thumb/8/85/MQ-9_Afghanistan_takeoff_1_Oct_07.JPG/1920px-MQ-9_Afghanistan_takeoff_1_Oct_07.JPG

INTEGRATING EW AND DE IN sUAS KILL CHAIN



DE Provides Engagement Options for Short Timelines and UAS Threat Evolution

DETECT

- Radar Cue
- ECM Cue
- Acoustic Cue
- Visual Cue

IDENTIFY

- Discriminate from bird(s) or other
- ECM Identify
- EO/IR Identify
- Ready HEL system

DECIDE

- Determine if Hostile
- Determine timeline (i.e. midair target)
- Decide to Engage via EW or DEW
- Collateral damage?

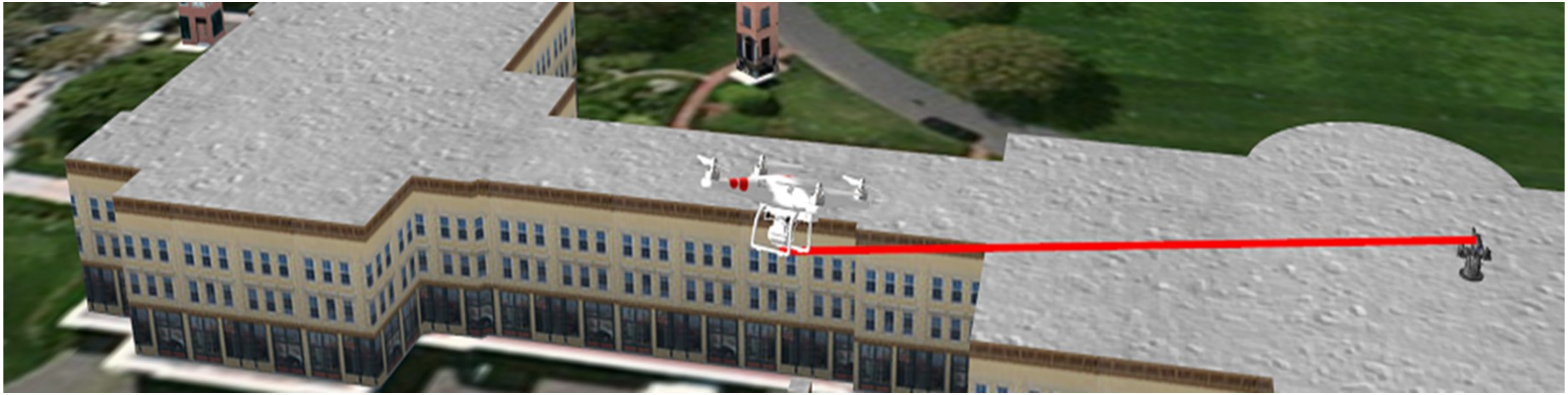
ENGAGE

- Engage w/EW (if time allows)
- Determine EW effectiveness
- Set point for DEW engagement?
- Airspace Deconfliction/PA?
- Engage with DEW capability

ASSESS

- Determine if UAS neutralized
- Re-Attack (Swarm)?
- Recover/Evaluate
- Notify authorities
- Resume operations

* Overall systems analysis and engagement timelines will dictate required timing of events.



DEW & EW FOR AERODROME DEFENSES: GETTING TO "YES"

- EW systems have long been integrated into combat through defined processes
- Increasing number of DEW systems going through formal deployment approval process
- Processes used for EW/DEW deployment must be adapted for civilian use

WHERE ARE WE TODAY?

- **Feb 2016 – Dec 2017:** FAA, DHS, DoD, and DoJ evaluated UAS detection capabilities near airports
  - FAA did not evaluate countermeasure capabilities for **safety**, **operational**, and **legal concerns**
- **2017 NDAA** authorized DoD to mitigate threat to military installations via *disrupt, disable, damage, or destroy*; and DoE to mitigate threats to nuclear facilities
- ***2018 FAA Reauthorization Act*** granted DHS and DoJ ability to address UAS threats to large-scale events and critical government facilities using Counter-UAS technology
- **Jul 2018 FAA Memo** regarding airport interests in counter-UAS technologies stated: "This [detection] technology is not ready for use in domestic civil airport environments" due to:
  - Primary factor: Not feasible do to number of sensors needed to achieve coverage
  - Potential [spectrum] interference impacts to UAS detection
  - High-level of manpower is required to operate systems
  - Concern for interference with safe airport operations
  - Belief that technology rapidly becomes obsolete upon installation

  True?
- **Dec 2018:** British Army used Israeli "Drone Dome" system to defeat UAS at Gatwick ["softkill"]

Demand for detection/mitigation capabilities increasing; need more education

FAA, Letter to Airport Sponsors providing guidance concerning UAS detection and countermeasure technology at airports, 19 Jul 2018; https://www.faa.gov/airports/airport_safety/media/Counter-UAS-Airport-Sponsor-Letter-July-2018.pdf ; https://www.wileyconnect.com/home/2017/8/8/new-dod-guidance-gives-military-green-light-for-counter-uas-measures; https://docs.house.gov/billsthisweek/20180924/HR302-2.pdf; https://www.uasvision.com/2019/01/02/rafaels-drone-dome-defeated-gatwick-drone/

HOW DO WE GET TO DESTRUCTIVE MITIGATION?

- **What decisionmakers need to know:**
  - Weapon system description, capabilities & limitations (Is it robust to CM?)
  - Specific threats to be countered, quantity/raid, and kill mechanism
  - Concept of operations (CONOPS)
  - Collateral damage risk, and mitigation techniques
  - Legal considerations, authorities, and Rules of Engagement (RoE)
  - Deconfliction requirements (with non-targets, and other aerodrome systems)

- **Risk:** Who accepts risk of EW/DEW system use?
- **Cost** is a significant driver for implementation. Who pays for systems/operations?

Decisionmakers want to know if a capability is adequate, feasible, and acceptable

https://www.cnbc.com/2019/01/08/why-airports-cant-stop-drone-disruptions.html

WEAPON SYSTEM DESCRIPTION?

- **Operational factors need to be understood:**
  - What are effectiveness coverage areas (detection/mitigation)?
  - Is the weapon an end-to-end standalone capability?
  - Fixed site or mobile?
  - Are subcomponents co-located or distributed?
  - What are the SWAP-C requirements?
  - What are the sustainment requirements?
  - Are their environmental limitations for the system?

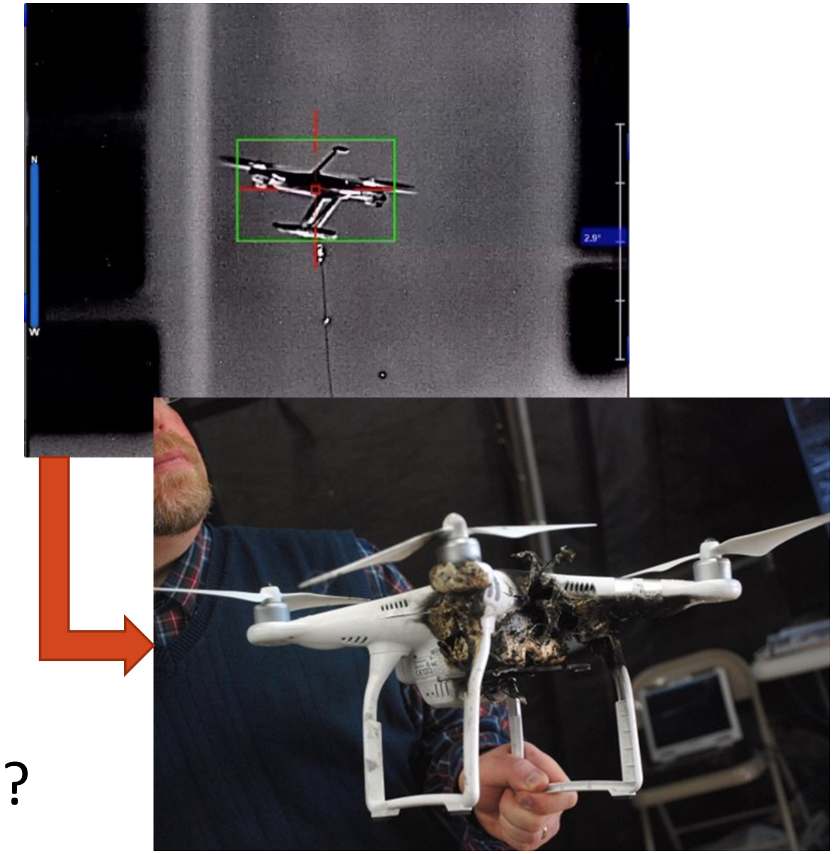
- **Personnel Requirements**
  - Who supplies operators and where do they “sit”? How many are required?
  - How is capability integrated into decision making?
  - How does the operator qualify and train?
- **Integration with Aerodrome Facility**
  - How does it leverage existing security infrastructure/architecture?
  - How is information shared between military/intelligence and law enforcement/security?

What does it take to get to initial operational capability?

https://www.forbes.com/sites/daveywinder/2019/01/04/dronegate-heres-what-really-needs-to-be-done-to-prevent-another-gatwick/#241f1f241c90; https://rdl.train.army.mil/catalog-ws/view/100.ATSC/9B8B46D7-719C-4E15-A8FE-9F2C1E278B88-1492434973380/atp3_01x81.pdf; https://www.cnbc.com/2019/01/08/why-airports-cant-stop-drone-disruptions.html

THE CONCEPT OF OPERATIONS?

- **Considerations for CONOP development:**
  - What are the operational vignettes?
  - Where is our engagement area?
  - What are the operational timelines?
  - What capabilities are meshed together?
  - What are the seams and overlaps?
  - Who are our partners and teammates?
  - What is the communication plan before, during, and after an engagement?
- Will need to develop a process to learn and improve?



We are breaking new ground in the commercial sector

https://www.cnbc.com/2019/01/08/why-airports-cant-stop-drone-disruptions.html

WHAT ABOUT COLLATERAL DAMAGE?

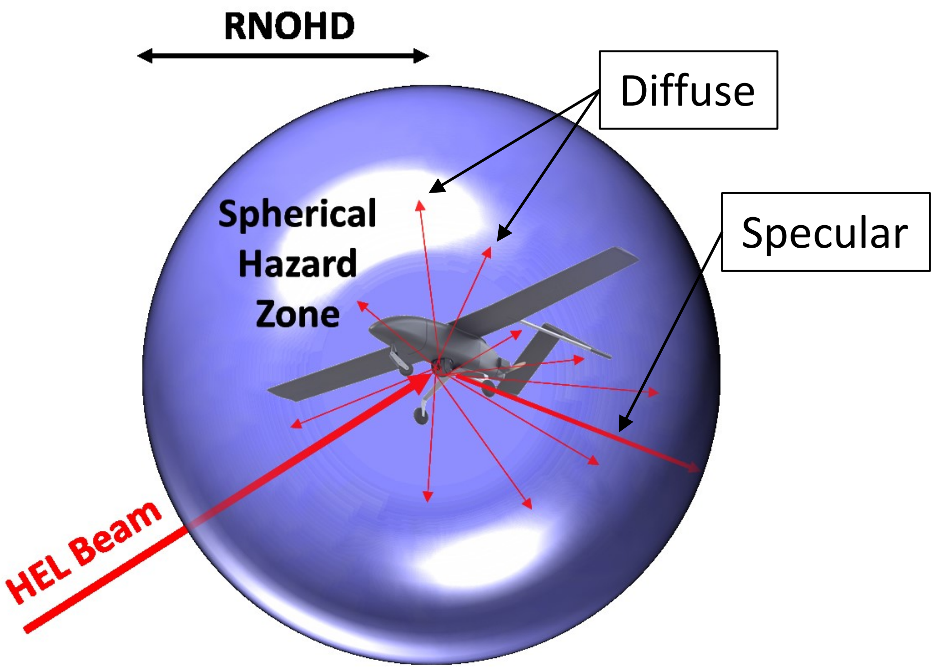
- **What is the collateral damage risk during an engagement?**
  - Need to ensure safe operation in vicinity of aircraft (scattering, EMI, overspill, etc.)
  - Need to understand location of protected populations, and their densities
  - Need to determine probabilities of negative impact; defines shot doctrine
  - Need to have clear lines of communications/authorities, and TTPs that are heavily rehearsed (training)
- **Steps can we take to mitigate collateral damage:**
  - Positively identify the threat: optics, RF signature
  - Control the engagement: timeline and threat profile dependent
  - Institute procedures to establish low-population “kill zones” for post-engagement UAS impacts (requires tactical decision aides)
- **Need to relate operational risk with impact of not doing anything**

The “cost of doing nothing” is appreciating

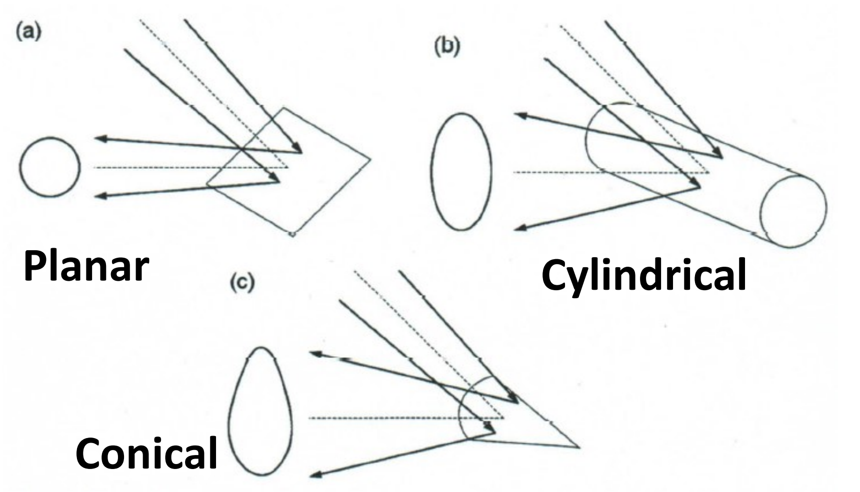
https://www.cnbc.com/2019/01/08/why-airports-cant-stop-drone-disruptions.html

HAZARDS OF REFLECTIONS OFF OF LASER TARGETS

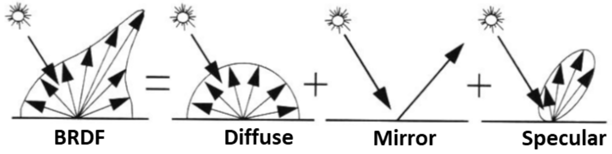
- Sphere drawn around target with radius equal to longest Hazard Distance (Reflected-NOHD)
- Any non-planar illuminated target surface will result in spreading out the reflected laser beam



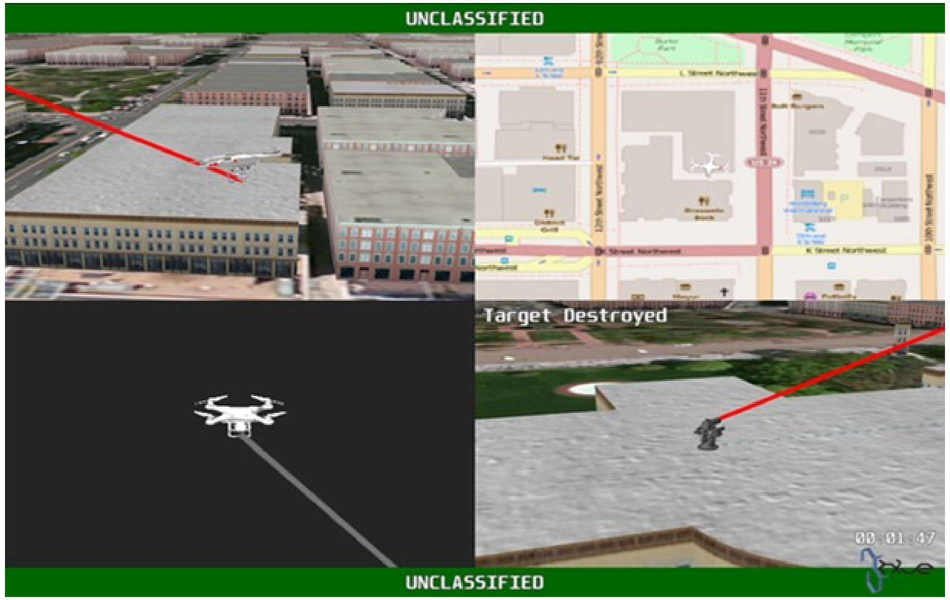
Target Shape Significantly Impacts Reflected Beam



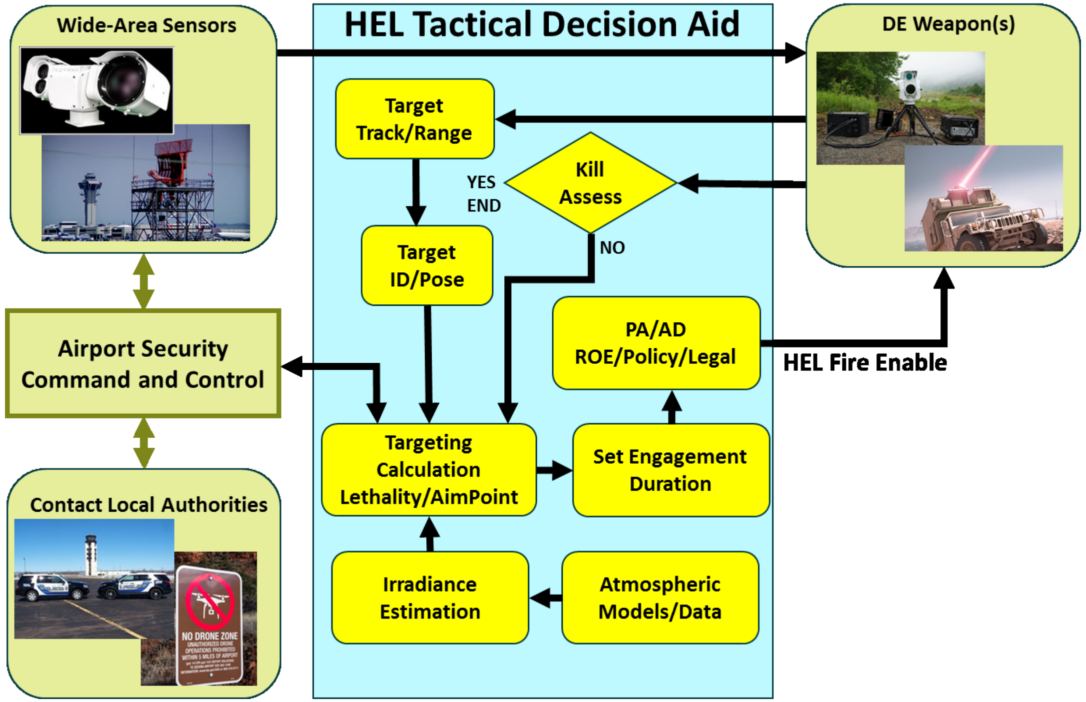
- Target movement, relative to the laser, reduces reflected-light exposure to observer (smaller NOHD)
- Dielectric material Bidirectional Reflectance Distribution Function (BRDF), with or without paint, are MUCH broader and lower in amplitude than metals
- **Reflected hazards are manageable; overspill mitigated by DE system**



TOOLS TO REDUCE COLLATERAL DAMAGE



- **Hybrid Integrated Visualization Engine (HIVE):** software program we have utilized for enterprise Modeling and Simulation (M&S):
  - High performance simulation integration
  - Analytical support and visualization
  - Support to operations and training



- **Tactical Decision Aid:**
  - Shortens Detect-to-Engage timeline through integration
  - Reduces complexity by increasing situational awareness
  - Incorporates ROE
  - Reduces collateral damage

Training, integration, and situational awareness improves operational effectiveness and reduces collateral damage

https://www.dsiac.org/resources/journals/dsiac/fall-2015-volume-2-number-4/hive-integrating-environment-simulation-and

WHAT ABOUT POLICY AND LEGAL CONCERNS?

- The left and right limits provided by policy and legal are constantly evolving to provide what is "best" for the majority of key stakeholders
- Assuming another drone attack will happen at an aerodrome in the near future, consider the following questions:
  - Are financial pressures from aerodrome disruption [e.g. Gatwick, EasyJet] sufficient to drive policy to change?
  - What conditions of a "lethal" drone attack would be sufficient to drive policy to change? Cost, casualties, other?
  - Assuming one aerodrome incorporates a destructive defensive system, what are the financial impacts to neighboring aerodromes, or nations, who do not?
- Will competition and regulation pressures on aerodromes lead to an "accepted" solution?

Policy is fluid, and likely to evolve, based on public pressures

https://www.cnbc.com/2019/01/08/why-airports-cant-stop-drone-disruptions.html

AUTHORITIES AND RULES OF ENGAGEMENT (RoE)

- There needs to be a clearly articulated message that establishes non-threatening and acceptable behaviors
- There needs to be a **strategic communication plan** that:
  - Clearly sets expectations for all stakeholders (UAV operators, aerodrome operators, travelers, and defenders)
  - Clearly articulates acceptable behavior and ramifications
  - Demonstrates conviction to the strategic communications
- There needs to be coordination and cooperation among all authorities (spectrum, aviation, law enforcement)
- The RoE should be clearly articulated, and consistent, within nations

Authorities and charters need to evolve as well

https://www.cnbc.com/2019/01/08/why-airports-cant-stop-drone-disruptions.html

WHAT ABOUT DECONFLICTION?

- **Deconfliction**: preventing EW/DEW systems from impacting ground operations, airspace operations, inadvertent illumination of space objects, and electromagnetic spectrum operations
- In their 2018 letter, the FAA articulated a number of concerns that are primarily related to deconfliction. (Note: These concerns have been addressed in fielded operational systems.)
- To incorporate aerodrome defenses we need to ensure we develop a plan to:
  - Eliminate electromagnetic interference of communications
  - Prevent electromagnetic interference to navigation aids and equipment
  - Minimize the impacts to airspace management and operations

One “fratricide” event can set this effort back

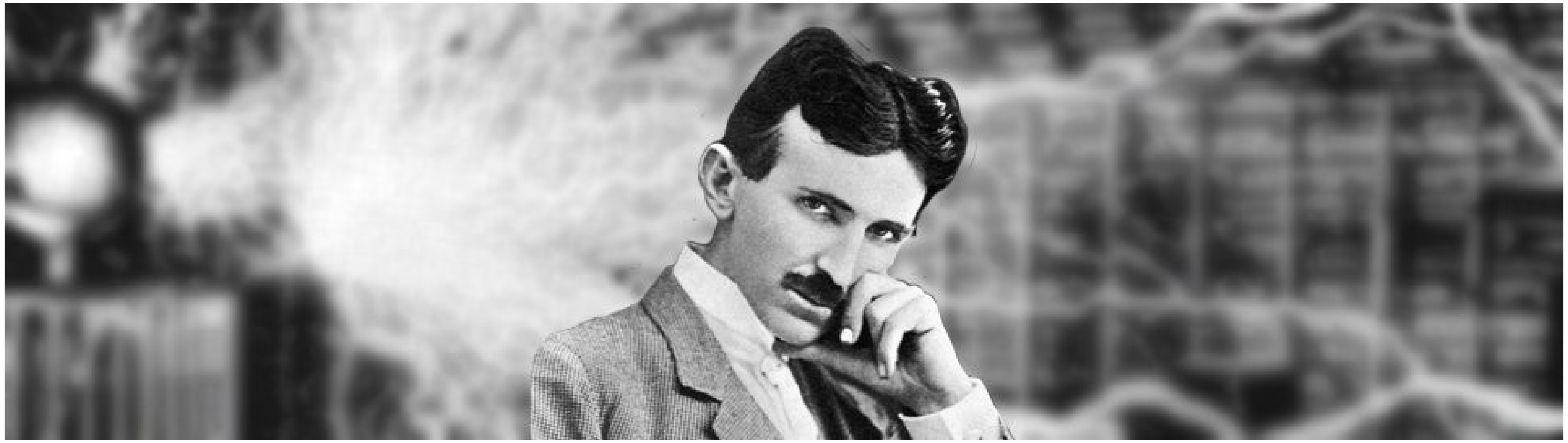
https://www.cnbc.com/2019/01/08/why-airports-cant-stop-drone-disruptions.html

Conclusion

- **UAS remain a <u>rapidly evolving</u> and <u>highly proliferating threat</u> to aerodromes; we cannot discount the possibility we are being attacked today**
- **EW/DEW provides versatility through proven enhanced sensors, precise engagements, and deep magazines**
- **There is enough knowledge and experience today to begin integrating directed energy weapons into Aerodrome operating environments**

http://mediacentre.britishairways.com/contents/archives/216/86/sites__cms/CI_BAHIS8453_58f77f776c732.jpg
https://www.anna.aero/2011/06/09/norwegian-joins-airberlin-germanwings-ryanair-and-sas-in-serving-berlin-stockholm-market/

QUESTIONS?



“Telautomata will be ultimately produced, capable of acting as if possest of their own intelligence, and their advent will create a revolution.”

– **Nikola Tesla**, My Inventions, first published in 1919 in the *Electrical Experimenter magazine*

The *Revolution* is Upon Us