Use of Small Unmanned Air Vehicles (Drones) to Enhance Aircraft Structural Integrity Programs

Walt Jarecki (ATF)

Bio

WALTER JARECKI
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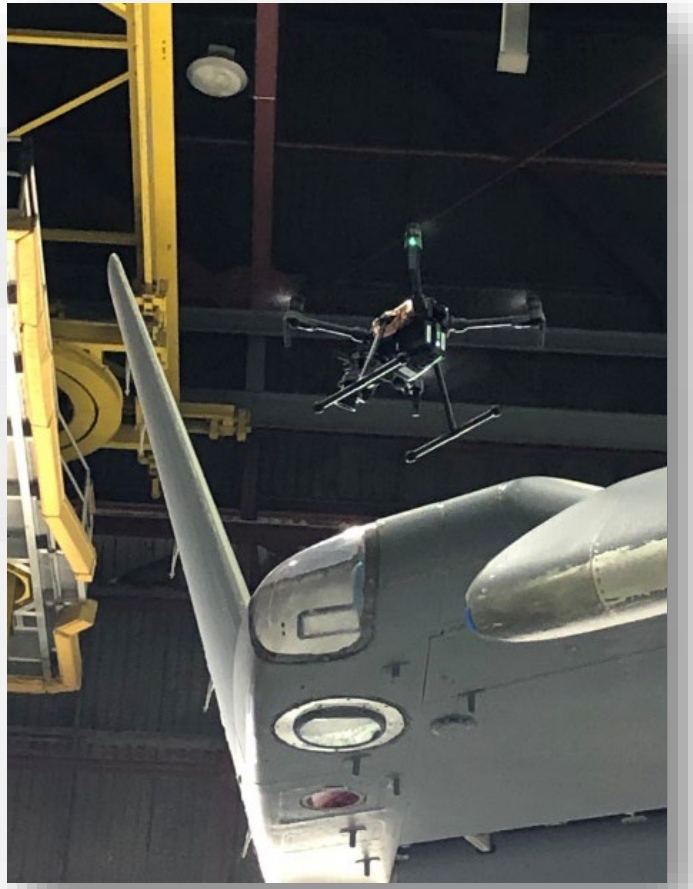
Airframe Customer Support

Walt is a service engineer with expertise in nondestructive testing methods for aircraft maintenance inspections. He has 30 years of aircraft wing and fuselage design experience on C-17, 787, 767-200/-300 BCF and 757 Eco Demonstrator technology demonstrator. Walt focuses on the adoption of new inspection technologies for aircraft maintenance inspections. Walt's vision is to reduce scheduled aircraft maintenance inspection task times by 50 percent by adopting inspection tools and processes that enable customer self-reliance and faster decision making. Effective integration of new inspection tools into maintenance operations will distinguish Boeing products from our competition. Walt holds a B.S in Aerospace Engineering from Iowa State University

Overview

- Situation
- Unleashing Value
- Testing
  - Boeing Activities
  - Manual Zonal GVI Process
  - Auto flight sUAS Assisted Zonal GVI - Process
  - Auto flight sUAS Assisted Zonal GVI - Operation
- Analysis
  - Human Factor Assessment
  - Data Collection with Auto flight sUAS
  - Monitor Resolution Requirement
  - Recommended Approach
- Results
  - sUAS Deployment Advantages and Risks
  - Setting Standards
  - Implementing Auto flight sUAS Assisted Zonal GVI
- Working with Metadata
- Industry Adoption
- Working Group
- Future Advancements



Situation

Airlines are requesting the use of Auto flight small Unmanned Aircraft Systems (sUAS) to complete aircraft inspections that improve safety and cost

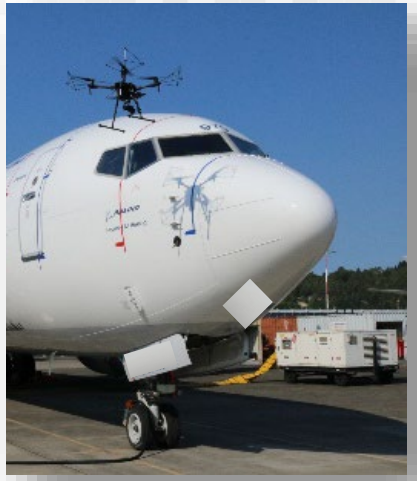
Current General Visual Inspection (GVI) methods require lifts causing injury risk and significant inspection time

The use of 2-D images to complete required aircraft inspections require human factors assessment, new skills and data delivery solutions

Visual analytics techniques supported by these image data streams will be a future standard incorporating camera images and machine learning to complete maintenance actions

Unleashing Value

- Improved drone platforms
- Improved safety and reduced cost
- sUAS Supplier/Boeing/Airline in work developments
- Predictive analytics to improve aircraft design and maintenance performance



Testing - Boeing Activities

- Boeing supports the use of Auto flight sUAS in maintenance task inspection

- Since 2019 Boeing has been conducting sUAS assisted aircraft inspection Equivalency tests
  - Goal is to prove sUAS assisted inspections are equivalent to mechanics manual inspections
    - Zonal General Visual Inspection (GVI)
    - A data set of standardized images that provide an opportunity to perform fault identification.
  - Aircraft condition images were captured in accordance with:
    - Flight plans
    - Locations
    - Camera specifications
- 2023
    - Auto flight image capture
      - Boeing Flight Plan/Supplier Flight Plan
      - Overlap/Coverage
      - Inspector image review traditional and supplier applications

Testing - Manual Zonal GVI Process

Data Collection

- Manual
- Labor Intensive
- Time consuming
- Unsafe to personnel or aircraft

Data Analysis

- Manual
- Subjective
- Inconsistent

Maintenance History

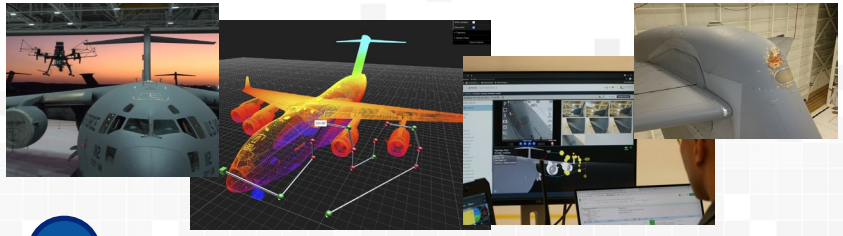
- Manual cataloging of damage in maintenance databases
- Must do manual research to find new vs old damages

Improve Maintenance Safety

Data Driven Engineering Insights

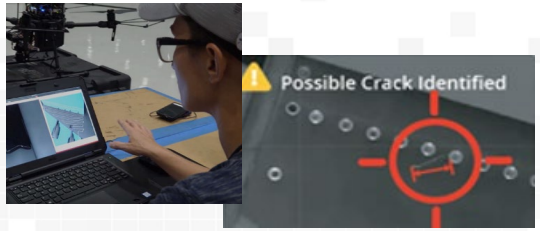
Build Regulator Trust

Testing – Auto flight sUAS Assisted Zonal GVI - Process



1 **Data Collection - Scan the Aircraft**

- HD camera mounted on drone
- Drone Auto flightly controlled
- Complete aircraft task cards with drone



2 **Image Analysis**

- Technician analyzes imagery to ID defects
- Damage detection software analyzes imagery
- Locate identified defects on a virtual 3-D aircraft

3 **Leveraging Data**

- Provide UI with damage detection software
- Tie to Boeing or host databases
- Validate/document damage

Solution Value

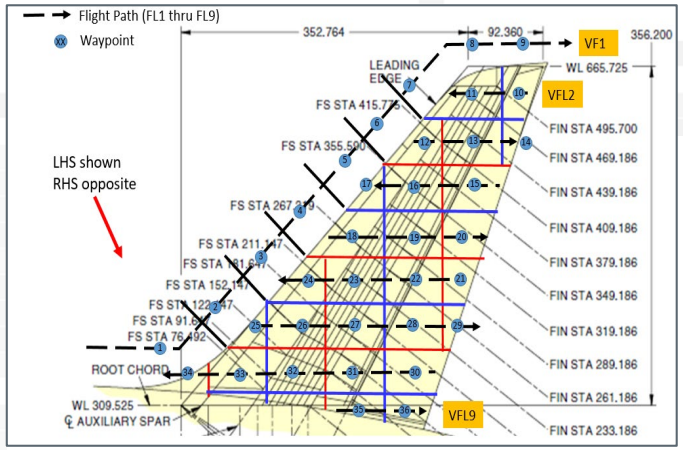
- **Increased safety** – reduced 80% of hazardous activities
- **Faster inspections** – >60% time savings
- **Manpower savings** – 50% reduction
- Efficiently manage damage/defect records and database
- Improve aircraft mission capability rates

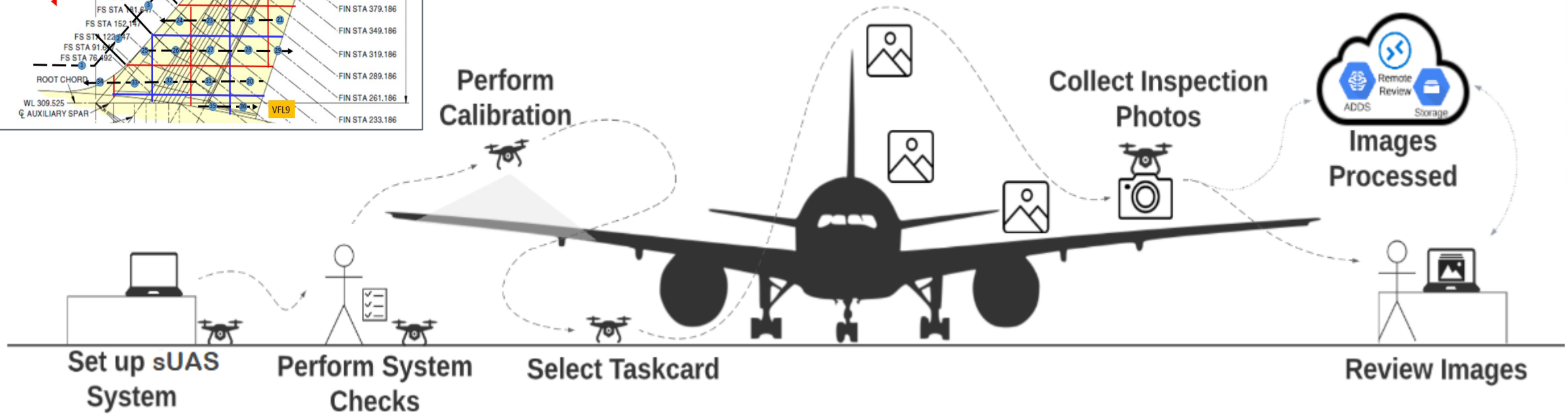
Use Cases

- **Scheduled inspections** (pre/post-flight, phase, GVI, etc.)
- **MRO pre-induction** scan for pre-existing damage/defects and wholistic state of aircraft at induction
- **Conditional Inspection** – Detailed Visual Inspection, Lightning Strike, Bird Strikes, Hail/Storm Damage, etc.

Testing – Auto flight sUAS Assisted Zonal GVI - Operation

Flight Path Waypoints

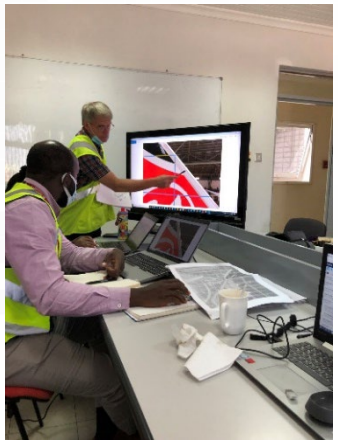


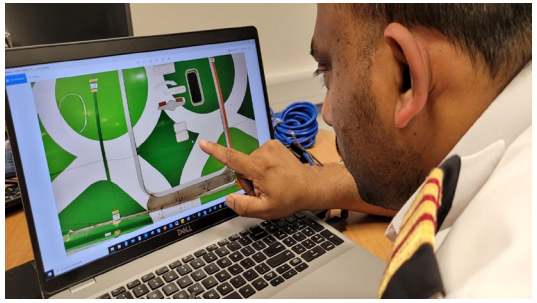


Analysis – Human Factor Assessment

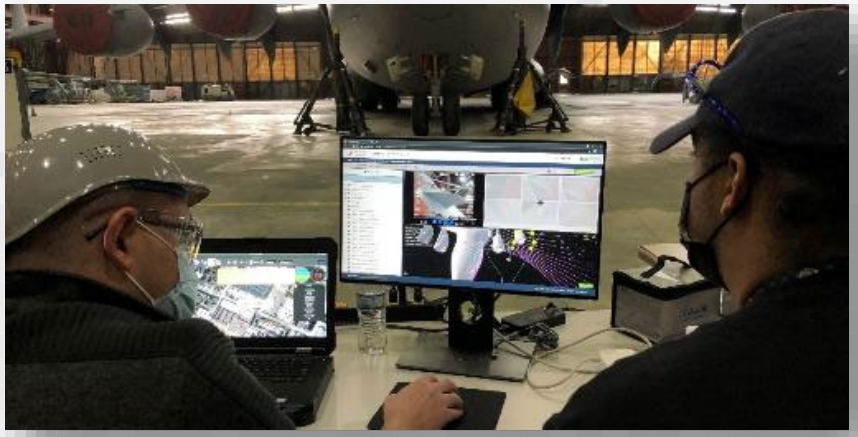
The following 11 Human Factors issues are based on the list of questions presented to the AMTs performing the Auto flight sUAS assisted Zonal GVI image review.

- Resolution Requirements for the imaging process
- Interpretation of 2-D vs 3-D images
- Basic image quality:
  - Blur, focus, overlap.
- Lighting quality and quantity
- Other available image enhancements
- Inability to use tools or touch
- Training for image review.
- Maintaining location awareness on aircraft in image set
- List of defect types
- Image interpreter fatigue and vigilance decrement
- The environment beyond visual:
  - Thermal
  - Auditory
  - Workspace design





Analysis - Data Collection with Auto flight sUAS



Graphical User Interface

Data Collection

Navigation

- **Auto flight**: sUAS takes off, locates and maps the aircraft using preplanned trajectories - “flight plan”

Inflight Monitoring

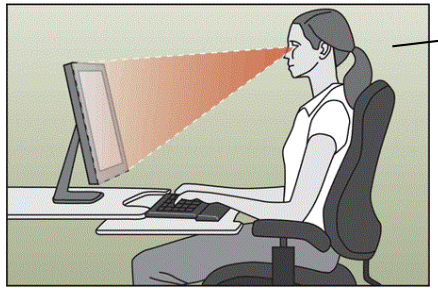
- Technician monitors inspection trajectories around aircraft
- Collects HD images tagged with 3-D location on aircraft

Analysis – Monitor Resolution Requirement

Human Factors Study

The better the screen size and resolution, affect the time spent by the Aviation Maintenance Technician (AMT) Inspector in zooming and panning.

Observing Distance from Monitor



Monitor
Screen
Diagonal
Length
Height
Resolution

Analysis - Recommended Approach

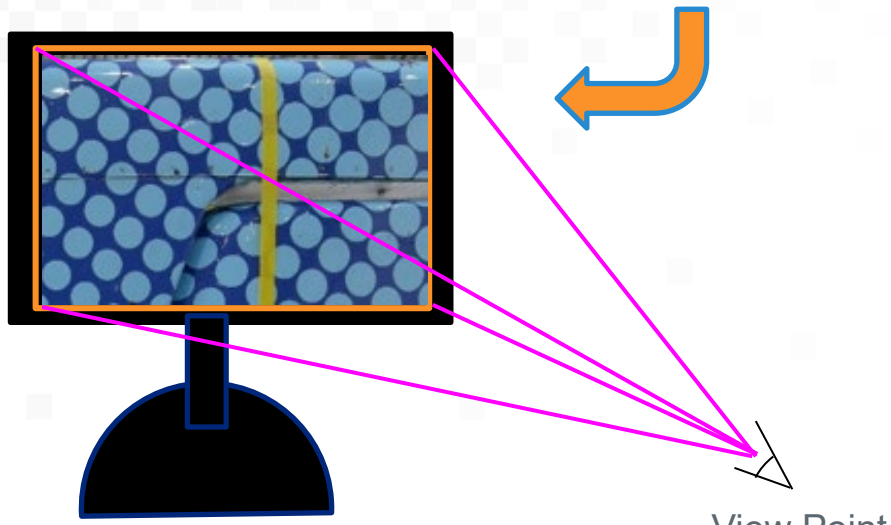
Standard GVI Outline Dimension

- The image should simulate as if it the AMT captured from touching distance
- Any zooming images may become blurry and pixelated
- Image inspection procedure criteria will be provided to AMT or UI

The Maintenance Steering Group-3 (MSG-3) GVI definition:

"Visual examination of an interior or exterior area, installation or assembly to detect obvious damage, failure or irregularity, made from within touching distance and under normally available lighting condition such as daylight, hangar lighting, flashlight or drop-light".

Adjustments for equivalency



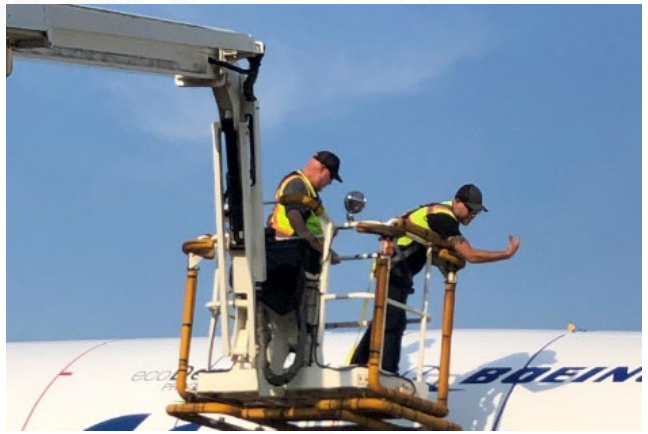
Results - sUAS Deployment Advantages and Risks

Economic:

Aircraft	UAV INSP Total Hours	Mechanic INSP Total Hours	Percent Reduction
A/C 1	8.89	21.62	58%
A/C 2	9.68	15.31	36%
A/C 3	9.65	25.18	61%
A/C 4	17.05	34.27	50%

Potential saving reduction in capitol expense for lift equipment

Safety:
Quality Management estimates 80% reduction of hazardous activities (working at heights)
Deploy safe sUAS environment in place of lift operations



- Automation:
- Consistency of inspection procedure
- Reduces unknown safety risk over manual flight operations

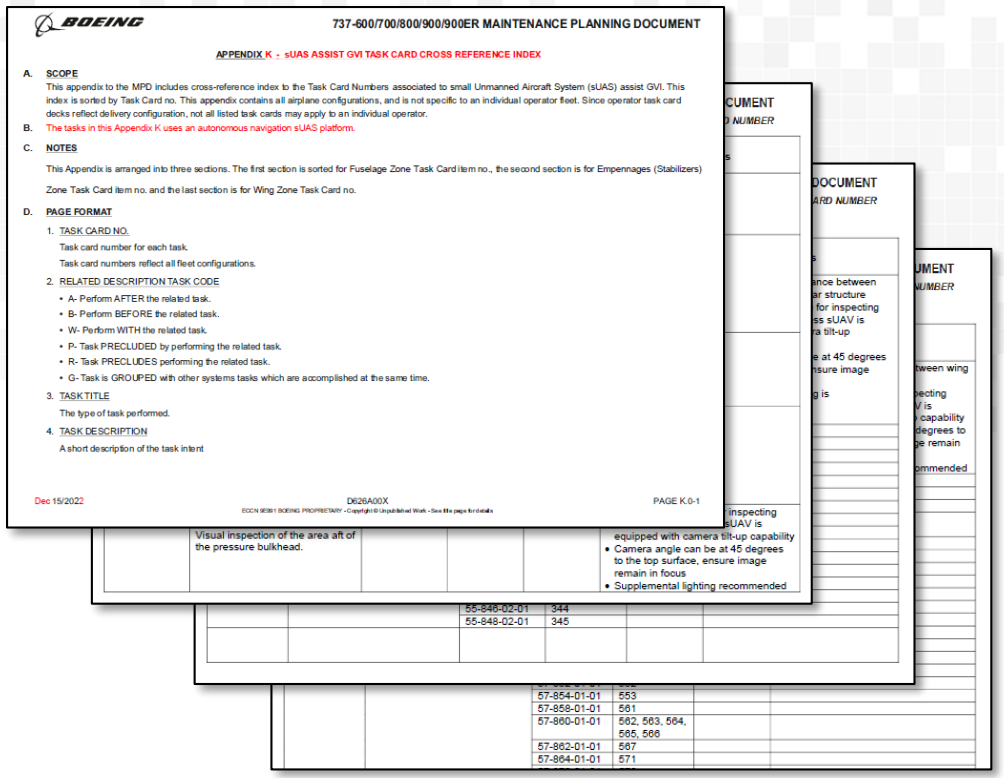
Results - Setting Standards

Boeing Industry Image Standard:

- Build a methodology to conduct 2-D image aircraft inspection
- The collected image data has been used to determine damage on aircraft
- Three analysis approaches where performed
  - AMT – Established ground truth (reported damage/defect)
  - Comparative analysis - Associate AMT finding to Auto flight sUAS assisted image finding
  - Machine Learning Trial - Demonstrated machine learning technology to aid and identify damage locations
- Conversion of human analysis to machine learning
  - Require extension damage identification and tagging to create a training material for the algorithm
- Human factors considerations are essential in assessment and analysis of 2-D images.

Results - Implementing Auto flight sUAS Assisted Zonal GVI

Maintenance Planning Document (MPD)



BOEING

737-600/700/800/900/900ER MAINTENANCE PLANNING DOCUMENT

APPENDIX K - sUAS ASSIST GVI TASK CARD CROSS REFERENCE INDEX

A. SCOPE

This appendix to the MPD includes cross-reference index to the Task Card Numbers associated to small Unmanned Aircraft System (sUAS) assist GVI. This index is sorted by Task Card no. This appendix contains all airplane configurations, and is not specific to an individual operator fleet. Since operator task card decks reflect delivery configuration, not all listed task cards may apply to an individual operator.

B. The tasks in this Appendix K uses an autonomous navigation sUAS platform.

C. NOTES

This Appendix is arranged into three sections. The first section is sorted for Fuselage Zone Task Card item no., the second section is for Empennages (Stabilizers) Zone Task Card item no. and the last section is for Wing Zone Task Card no.

D. PAGE FORMAT

1. TASK CARD NO.
   Task card number for each task.
   Task card numbers reflect all fleet configurations.
2. RELATED DESCRIPTION TASK CODE
   - A- Perform AFTER the related task.
   - B- Perform BEFORE the related task.
   - W- Perform WITH the related task.
   - P- Task PRECLUDED by performing the related task.
   - R- Task PRECLUDES performing the related task.
   - G- Task is GROUPED with other systems tasks which are accomplished at the same time.
3. TASK TITLE
   The type of task performed.
4. TASK DESCRIPTION
   A short description of the task intent

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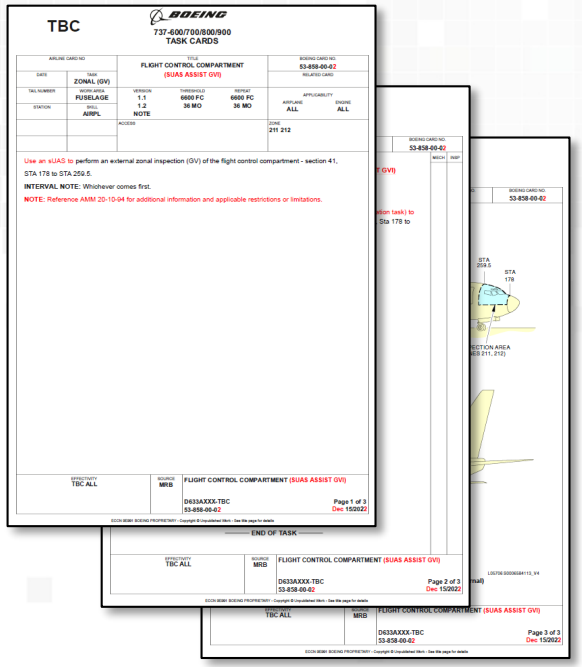
Task Cards (TC)



TBC

BOEING

737-600/700/800/900 TASK CARDS

FLIGHT CONTROL COMPARTMENT (SUAS ASSIST GVI)

ZONAL (GV)

FUSELAGE

AIRPL

53-858-00-02

6600 FC 36 MO

6600 FC 36 MO

ALL

ALL

211 212

Use an sUAS to perform an external zonal inspection (GV) of the flight control compartment - section 41, STA 179 to STA 259.5.

INTERVAL NOTE: Whichever comes first.

NOTE: Reference AMM 20-10-94 for additional information and applicable restrictions or limitations.

END OF TASK

EFFECTIVITY TBC ALL

SOURCE MRB

D633AXXX-TBC 53-858-00-02

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Page 3 of 3 Dec 15/2022

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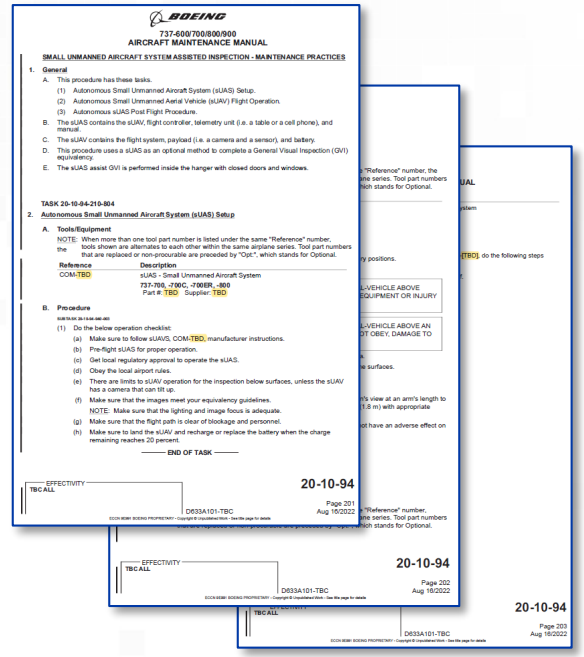
Aircraft Maintenance Manual (AMM)



BOEING

737-600/700/800/900 AIRCRAFT MAINTENANCE MANUAL

SMALL UNMANNED AIRCRAFT SYSTEM ASSISTED INSPECTION - MAINTENANCE PRACTICES

1. General
   A. This procedure has these tasks.
      (1) Autonomous Small Unmanned Aircraft System (sUAS) Setup.
      (2) Autonomous Small Unmanned Aerial Vehicle (sUAV) Flight Operation.
      (3) Autonomous sUAS Post Flight Procedure.
   B. The sUAS contains the sUAV, flight controller, telemetry unit (i.e. a table or a cell phone), and manual.
   C. The sUAV contains the flight system, payload (i.e. a camera and a sensor), and battery.
   D. This procedure uses a sUAS as an optional method to complete a General Visual Inspection (GVI) equivalency.
   E. The sUAS assist GVI is performed inside the hanger with closed doors and windows.

TASK 20-10-94-210-804

2. Autonomous Small Unmanned Aircraft System (sUAS) Setup

   A. Tools/Equipment

   NOTE: When more than one tool part number is listed under the same "Reference" number, the tools shown are alternates to each other within the same airplane series. Tool part numbers that are replaced or non-procurable are preceded by "Opt.", which stands for Optional.

Reference	Description
COM-TBC	sUAS - Small Unmanned Aircraft System 737-700, -700C, -700ER, -800 Part #: TBD Supplier: TBD

   B. Procedure

   (1) Do the below operation checklist:
      (a) Make sure to follow sUAVS, COM-TBC, manufacturer instructions.
      (b) Pre-flight sUAS for proper operation.
      (c) Get local regulatory approval to operate the sUAS.
      (d) Obey the local airport rules.
      (e) There are limits to sUAV operation for the inspection below surfaces, unless the sUAV has a camera that can tilt up.
      (f) Make sure that the images meet your equivalency guidelines.
      NOTE: Make sure that the lighting and image focus is adequate.
      (g) Make sure that the flight path is clear of blockage and personnel.
      (h) Make sure to land the sUAV and recharge or replace the battery when the charge remaining reaches 20 percent.

END OF TASK

EFFECTIVITY TBC ALL

D633A101-TBC

20-10-94

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Working with Metadata

GPSLatitude	47 deg 32' 23.93" N
GPSLatitudeRef	North
GPSLongitude	122 deg 18' 58.42" W
GPSLongitudeRef	
GPSLongtitude	
GPSPosition	
GPSVersionID	
HasCrop	
HasSettings	
HyperfocalDistance	
ImageHeight	
ImageSize	
ImageWidth	
ISO	
LensID	
LensInfo	
LensMake	
LensModel	
LightSource	
LightValue	
LinearizationTable	
LinearResponseLimit	
LocalizedCameraModel	
Make	
MaxApertureValue	
Megapixels	
MeteringMode	
MIMEType	
Model	
ModifyDate	

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FileSize	
FileSource	
FileType	
FileTypeExtension	
Flash	
FlightPitchDegree	
FlightRollDegree	
FlightXSpeed	
FlightYawDegree	
FlightYSpeed	
FlightZSpeed	
FNumber	
FocalLength	
FocalLength35efl	
FocalLengthIn35mmForm	
Format	
FOV	
GainControl	
GimbalPitchDegree	
GimbalReverse	
GimbalRollDegree	
GimbalYawDegree	
GPSAltitude	
GPSAltitudeRef	

CFAPattern	[Red,Green][Green,Blue]
CFAPattern2	0 1 1 2
CFAPlaneColor	
CFARepeatPatternDim	
CircleOfConfusion	
ColorMatrix1	
ColorMatrix2	
Compression	
Contrast	
CreateDate	
CreatorTool	
CustomRendered	
DateCreated	
DateTimeOriginal	
DefaultCropOrigin	
DefaultCropSize	
DefaultScale	
DefaultUserCrop	
DigitalZoomRatio	
Directory	
DNGBackwardVersion	
DNGLensInfo	
DNGPrivateData	
DNGVersion	
ExifByteOrder	
ExifToolVersion	
ExifVersion	
ExposureCompensation	
ExposureMode	
ExposureProgram	

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Aperture	5
ApertureValue	
AsShotNeutral	0.3492496589 1 0.5651214128
BaselineExposure	0
BaselineNoise	1
BaselineSharpness	1
BayerGreenSplit	0
BestQualityScale	1
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BlackLevelRepeatDim	2 2
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CalibratedOpticalCenterX	
CalibratedOpticalCenterY	
CalibrationIlluminant1	Standard Light A
CalibrationIlluminant2	D65
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CameraRoll	
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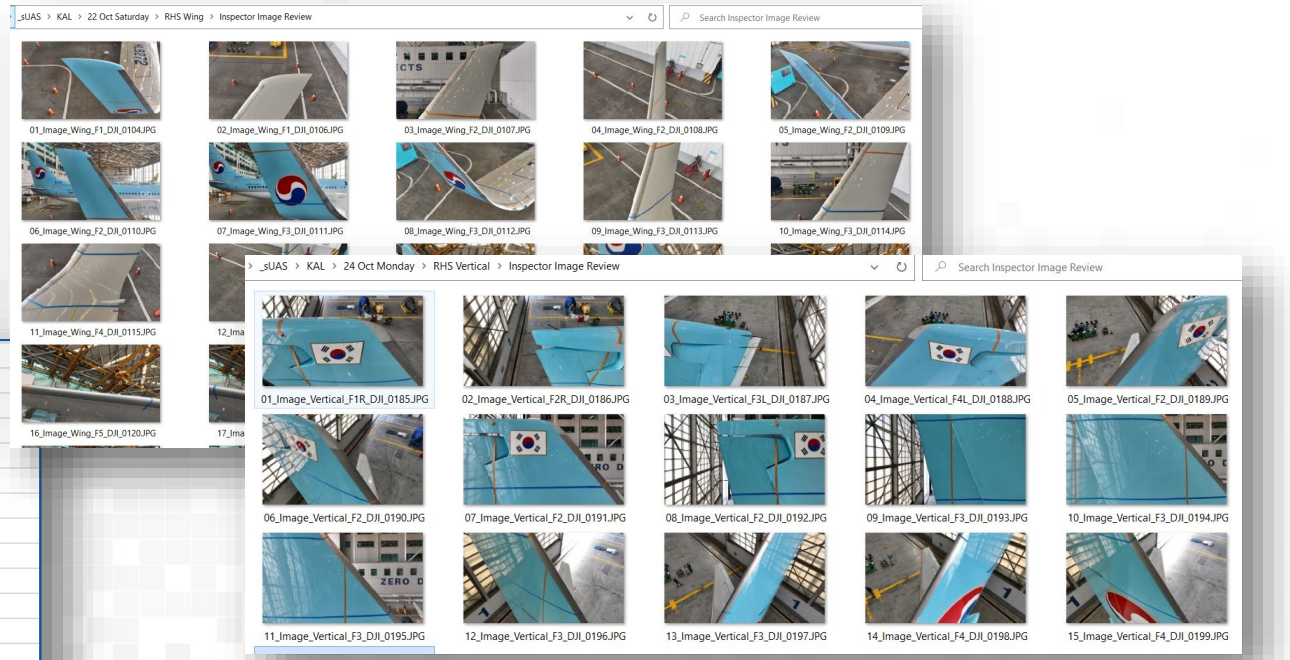
CameraYaw	
CamReverse	0
CFALayout	Rectangular

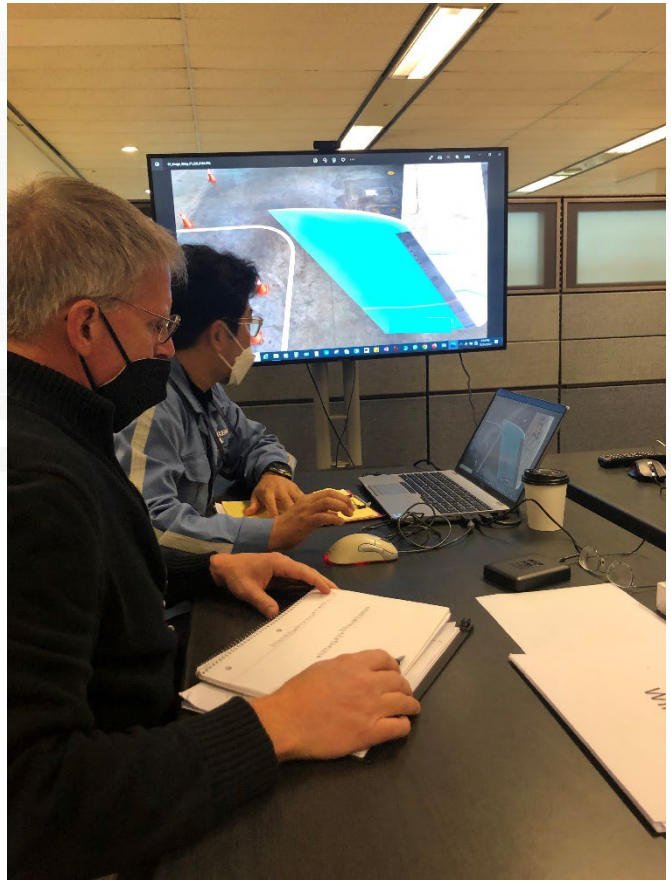


Leveraging image's metadata for predictive analysis to improve aircraft design and maintenance performance.

Industry Adoption

Establish a safety culture

- Supplier sUAS and OEM partnership for sUAS inspection development
- Supplier sUAS system operation training
- OEM remote inspection procedure guidelines
- Environmental and workload factors



Working Group -Certification and Operational Approval Approach

Proposal presented to Working Group (WG)

Working Group

FAA AFS-300
FAA AED
Airline
Boeing

14 Airlines
8 regulators

sUAS Assisted Aircraft Inspection Working Group # 1

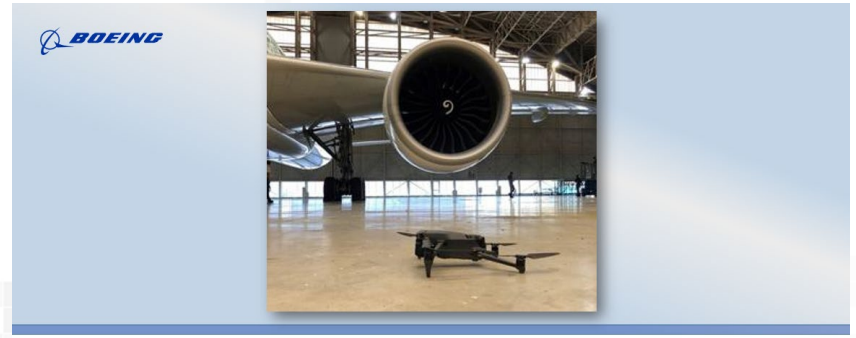
Mike Eckelberry | Working Group Focal

April 26, 2022

sUAS Assisted Aircraft Inspection FAA Meeting

Mike Eckelberry | FAA/Working Group Focal

Jan 31/ Feb 1 2023



sUAS Assisted Aircraft Inspection Working Group # 2

Mike Eckelberry | Working Group Focal

September 12-15, 2022

sUAS Equivalency Program Familiarization - Overview

Aircraft OEM | Regulator | sUAS Supplier | Airline | Human Factors

sUAS Equivalency Test Program

- ❑ Gather inspection data (automated operation on in-service aircraft)
- ❑ Establish human eye baseline
- ❑ Prove sUAS assisted inspections are equivalent to current manual methods

Cooperative Industry Effort

Proposed: Equivalency agreement in WG

Alternate: Industry Committee

Future Project Explorations

- Outdoor Auto flight sUAS operation
- Lightning Strike and Hail (Dent) Auto flight sUAS Conditional Inspection Testing
- Incorporation of several advance technologies:
  - Damage identification and size
  - Generated repair instructions
  - Cloud based storage/retrieval
  - Sensor payloads