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Human / Automation Collaboration in Aviation NDT

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Why Human/Automation Collaboration?

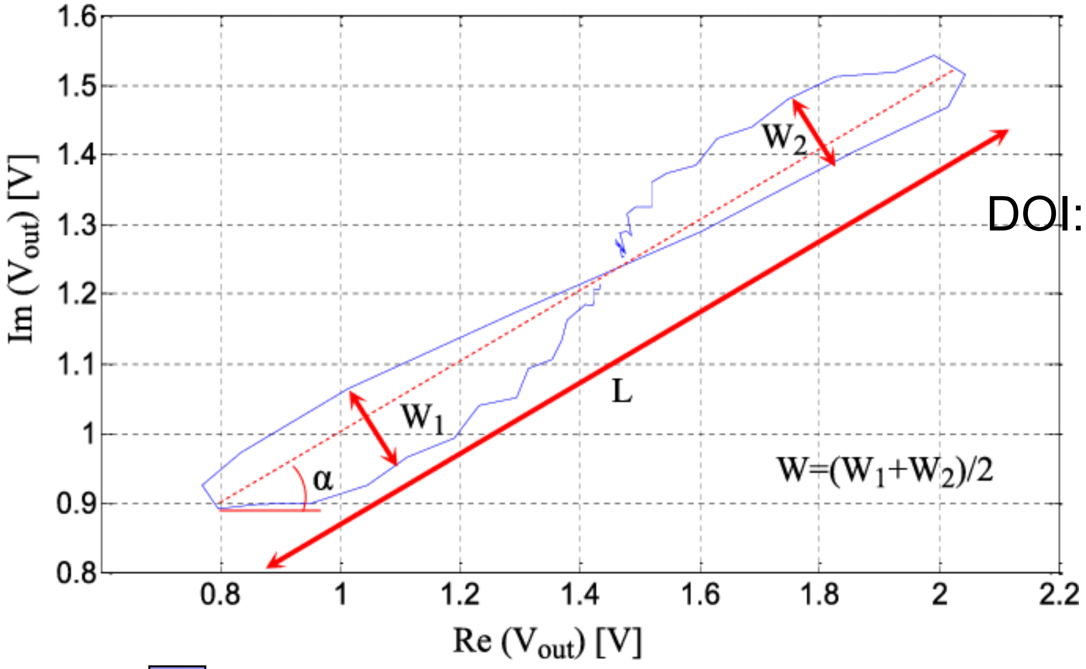
- Almost total automation of inspection (including NDT) in many forms of mass production has replaced the human inspector.
- Unaided visual inspection is still used for in-service inspection, particularly in aerospace.
- Most aviation NDT lies between these extremes!
- Humans and automation both make errors so the challenge is to use the best capabilities of both.

NDT and Automation develop in Parallel

- Improvements in NDT for aviation have a long history.
- Some have been mechanical or electrical improvements, some have been automation, e.g., signal processing software, displays.
- This continues: Just search Google for *Automation in NDT* and see the ads for products!

Automation for Human Use

For many years now, automation has helped the human inspector, e.g., by replacing Lissajous Figures with Veridical Displays For Eddy Current Inspection. These can be much easier for the inspector to interpret.



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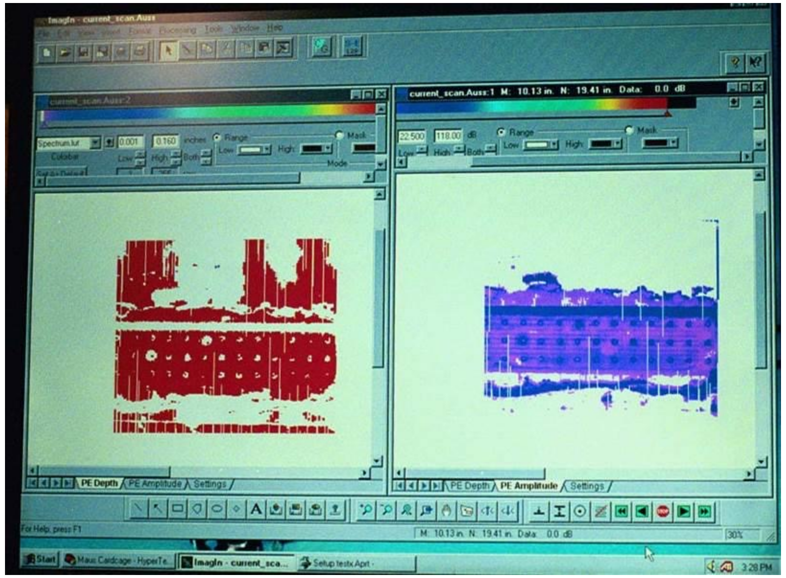


From Drury, C. G. Handbook of System Reliability in Airframe and Engine Inspection. FAA, 2005

Now have Many Choices: How to Choose?

- Many technical papers start from the premise that the human inspector is error prone, while automation is not.
- The real issue in maximizing performance is to get the human and automation to do what they each do best.
- Known in Human Factors as “Allocation of Function”, i.e., allocate each function in inspection to either human or machine, then design the interface between them.
- Now more urgent with Artificial Intelligence / Machine Learning (AI/ML)

What are “Functions” in Inspection?

- For any inspection task we can separate 5 functions:
  Set-up, Access, Search, Decision, Response.
- Set-up: Assemble tools, procedure, train inspector
- Access: Bring the inspector and inspected item together
- Search: Move the sensor so as to cover the whole item
- Decision: If an indication is found in Search, decide whether or not it requires action.
- Response: Take the required action, then continue search.

Which Functions are most Error-Prone?

- Set-up, Access and Response are typically routine procedures and thus quite reliable.
- Search and Decision are both more prone to failure, whether allocated to human or machine.
- Old Research: Hou, Lin and Drury (1993) tested different allocations directly with ML algorithm for automation.
- Found that neither full human nor full automation performed as well as a hybrid system.
- But ML has come a long way since then!

What is Known about Functions?

- Good numerical predictive models* of humans performing both Search and Decision components.
- These tell us how people perform these functions and how factors of the task affect performance
- Using these models we can see what role human inspectors should play in a human/automation collaboration.
- * [Drury, C. G., (2021). Human-Systems Integration in Aerospace NDT, Keynote Address to 13th International Symposium Aerospace NDT, Williamsburg, VA, October 2021. Virtual by ARCTOS (AeroNDT 2021) Vol. 27(6)]

An Unusual Current Example: UAVs for GVI

- Much interest in recent years in using small UAVs to collect visual data for external inspection of aircraft.
- Global market $23B by 2027 across all industries (https://www.marketsandmarkets.com/PressReleases/drone-inspection-monitoring.asp)
- Several companies advertise systems and performance enhancement, as well as improved safety.
- Good technical literature on UAV assisted inspection of bridges, buildings, wind turbines and (YES!) aircraft.
- …but not much direct evaluation of detection performance.

Performance Measures in Literature

- Most papers do not provide detection performance.
- Papa & Ponte (2018) claim (w/o data) to be able to detect simulated hail strike and lightning strike.
- Two (Novak, 2020, 2021) use a UAV for pre-flight inspection of a Part 145 aircraft, and also claim that their video processing algorithm of UAV data allows anomalies to be detected
- Literature emphasis is mainly on detection algorithms.

How the System Works

- The UAV is programmed to fly a given path, collecting images at known points.
- Images are inspected using a computer display by human inspectors and/or algorithms for specified defects.
- Recent paper on detection of loose/missing screws is typical.

Miranda, J., Larnier, S., Herbulot, A. & Devy, M. UAV-based Inspection of Airplane Exterior Screws with Computer Vision. *14h International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications.*, Feb 2019, Prague, Czech Republic. hal-02065284

A UAV Application: General Visual Inspection

- GVI is used routinely by operators/repair stations for incoming and outgoing inspection of (mainly) exteriors.
- Defined by MSG-3 as: 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… (Full definition next slide)
- Note the potentially large number of defect types and the lack of specific numerical criteria for reporting. Also, any deviation from the definition potentially invalidates the GVI.

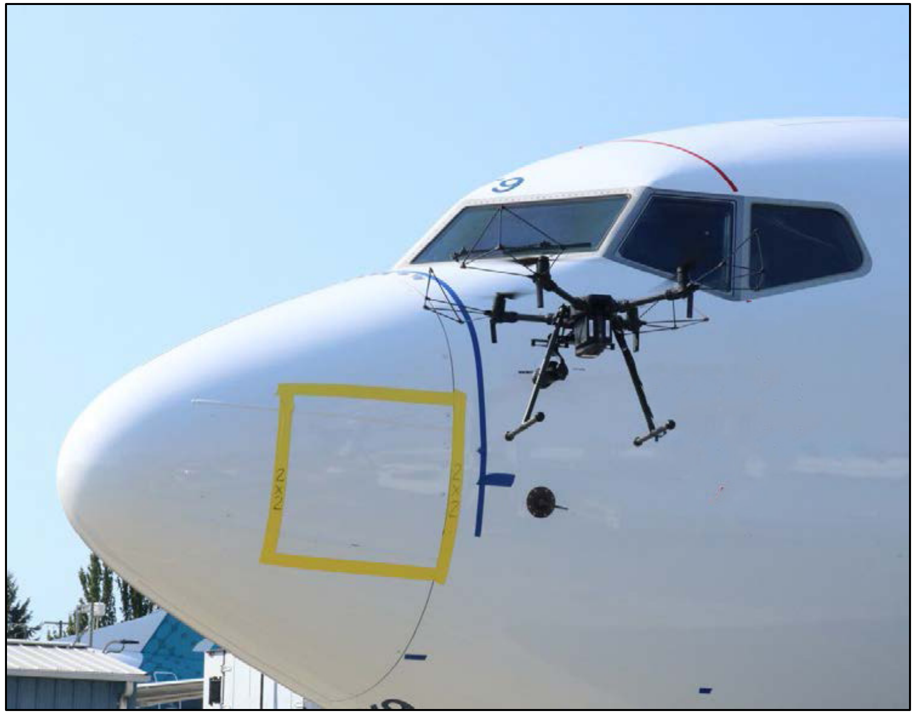
appropriate visibility.

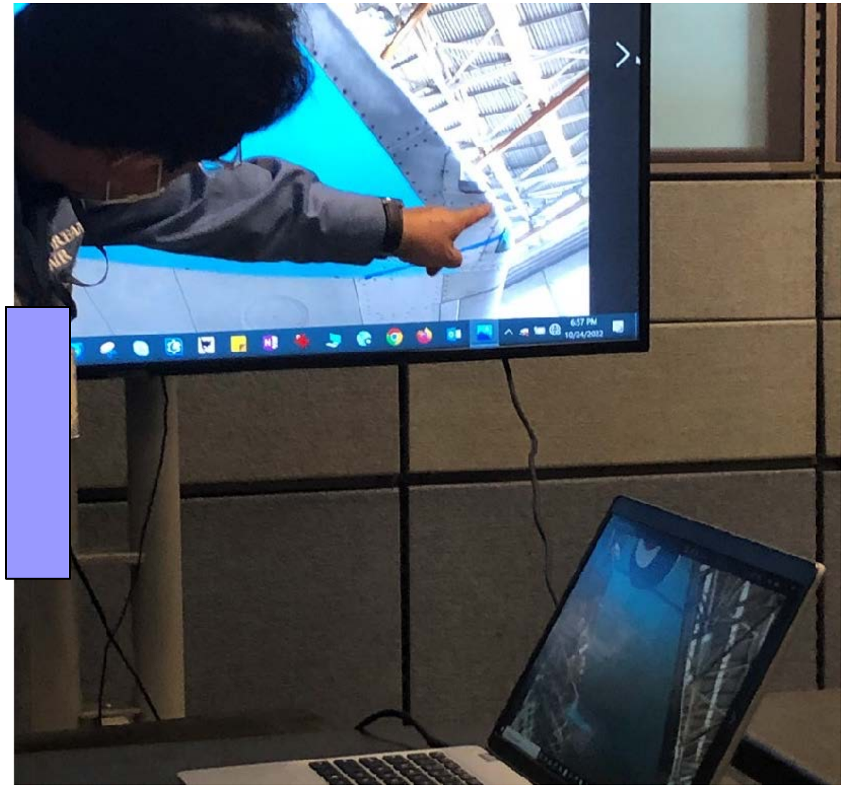
Full Definition of General Visual Inspection

"A visual examination of an interior or exterior area, installation or assembly to detect obvious damage, failure or irregularity. This level of inspection is made from within touching distance unless otherwise specified. A mirror may be necessary to enhance visual access to all exposed surfaces in the inspection area. This level of inspection is made under normally available lighting conditions such as daylight, hangar lighting, flashlight or drop-light and may require removal or opening of access panels or doors. Stands, ladders or platforms may be required to gain proximity to the area being checked. Basic cleaning may be required to ensure appropriate visibility".

Manual GVI

UAV-Assisted GVI: Image Capture





UAV-Assisted GVI: Image Review

Images Courtesy of W. Jarecki

Hard to Establish Manual vs. UAV Performance

- No defect list / No numerical standards / No PoD curves.
- Empirical studies typically have no ground truth data: Just "Manual found these defects / UAV-assisted found these other defects".
- We CAN compare empirically, but defects found differ in type so direct comparison difficult.
- Can use simulated defects for "Ground Truth" but inspectors are wise to non-typical defects.

A Different Way?

- If direct performance comparison is problematic, can we use another way to make a valid comparison?
- One idea: Compare the *task* between manual and UAV-Assisted GVI.
- The inspector (often an AMT) should have the *same potential* for finding defects in both systems.
- Are factors known to affect performance the same or different: Task, Human, Interface, Environment, Social?

Task Factors

- Manual: Eyes at arm’s length from surface, Able to move body & head to take advantage of surface reflections, Able to use auxiliary lighting e.g. flash light at grazing incidence to enhance some defects.
- UAV-Assisted: AMMT’s eyes an unknown distance from screen, AMT cannot move body or head to change specular reflections, AMT cannot use auxiliary lighting.

Human Factors

- Manual: AMTs trained on GVI in college but little specific training on site, AMTs can request feedback on defects after they are further examined and rectified, Vison tested regularly.
- UAV-Assisted: No specific training given on site, Feedback still possible if requested, Vision tested regularly.

Interface Factors

- Manual: Very familiar interface, intuitive movement during Search, can use flashlight and body/head movements to aid both Search and Decision.
- UAV-Assisted: Partially-familiar interface, Learned movement during Search, No use of movement of flashlight to aid Search or Decision

Environment Factors

- Manual: Exposed to heights and slipping hazards, Must have spotter while moving work-stand/Hi-Lift, Hangar thermal and visual environment may not be optimal
- UAV-Assisted: Review images in safer office/lab environment, Spotter needed during initial UAV image capture, Easy to optimize thermal and visual environment.

Social Factors

- Manual: Considerable activity around the workplace, AMT may be interrupted to perform other tasks, Tasks typically take longer than UAV-Assisted Review
- UAV-Assisted: Often alone in environment, Rare to be interrupted while not visible in the hangar, Shorter, but more concentrated, working time.

Some you win, Some….

- Looking at the list of Manual vs. UAV-Assisted, some factors favor each one.
- UAV-Assisted has little fall risk, and inspection takes place in a better environment.
- Manual has defined visual characteristics, trained inspectors and the ability to move head, body and flashlight to improve performance
- Can we mitigate adverse factors of UAV-Assisted GVI?

Example: Visual Factors in UAV-Assisted

- Principle: At least do not degrade visual performance during image capture and display.
- We know what is the resolving power of the human eye: about 1’ of arc. That should be preserved as one pixel on the camera sensor, and on the final display. With “arms length” data, these define sensor size, display size etc.
- Head/body movement can be simulated by overlap of images to effectively place any specular reflections in different places on adjacent images.

Example: Human Factors in UAV-Assisted

- Training will improve performance in UAV-Assisted GVI – we know because researchers say they have learned much about what specific defects look like on a screen. This knowledge can be passed on through an appropriate (short) training program.
- UAV-Assisted inspectors can share insights and results of feedback to achieve constant improvement early in implementation.

Example: AI/ML Assistance in UAV

- Most of the technical literature is more concerned with using AI/ML to *eliminate* human inspection.
- BUT, AI/ML may well be appropriate for some defects at some on-aircraft locations.
- We can combine a AI/ML interpretation of those conditions to improve overall Human Automation Collaboration in GVI.

Conclusions

- There is an existing framework for how to achieve Human Automation Collaboration in NDT: Allocation of Function.
- This can ensure that the best aspects of both can be combined to enhance system performance.
- Even odd use-cases, such as the restrictions in GVI, can be accommodated with attention to HOW to design the system for both human and automation

Thanks for inviting me to help tackle this important issue.

Best wishes from Boulder for the rest of the meeting!