On the Use of Visualization Tools to Present Complex Simulated Environmental Data for Policy Making

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Abstract — **The future of aviation is the subject of considerable debate and policy discussion. There is also increasing emphasis on the inclusion of public consultation and participation within the planning and decision making system. Yet, presenting the findings of complex, multi-dimensional research in a style that is accessible by a potentially lay audience is no simple challenge. This is especially true for subjects whose findings are controversial, such as airport expansion plans and possible health implications of activities.**

Text heavy documents laden with equations, graphs and tables will in most cases act only to alienate a non-expert. However, a method that has found favor in presenting to the non-expert is the use of visualizations, particularly visualizations that allow for a degree of interactivity. This paper investigates a number of the barriers that exist between science and policy making, and then proposes the virtualization application Google Earth as ideally suited for presentation of aviation-related subjects. The paper includes examples of Google Earth models which make use of the 3D capabilities of the tool combined with streamed geographical content to provide stakeholders with a novel, intuitive and interactive presentation that requires no expert understanding to convey its findings.

Keywords-Environmental policy, aviation, visualization, science-policy divide, lay audience, Google Earth

I. Introduction

While the emissions of most industries are anticipated to decrease over the coming decade, air passenger traffic and consequently the impact of aviation on the environment is projected to rise [1]. This has generated a significant increase in media and public attention on the growing needs to establish policy that better mitigates aviation's environmental impact. Subsequently, environmental controls have been highlighted as a threat to future capacity [2,3]. However, the creation of mitigation strategies is no easy task.

In order for science to contribute to policy making decisions, research findings must be communicated to stakeholders. Engel-Cox [4] summarized that scientific data intended for use in the creation of policy needs to meet 5 essential criteria if it is to be useful: *relevance, timeliness, integrity, clarity, and visualization*. While relevance and timeliness are tied into the project definition, integrity, clarity and visualizations are the responsibility of the researcher. Furthermore, increased awareness has placed a greater motivation to include public consultation in the decision-making process. This increases the number of potential lay recipients of scientific data and means the ability to present scientific conclusions in a manner that is accessible to non-experts is even more important. Still, the utilization of visualization techniques is often ignored and it remains the norm for researchers to publish their findings in long technical documents or journal papers that are difficult to understand by all but a few specialists. This is specifically true of the multi-dimensional data generated by complex mathematical simulations. This generates an understandable divide between the scientific and lay communities which hampers the exchange of information from one camp to another.

There is an increasing body of literature that seeks to expose the underlying causes of this barrier between science and successful policy making. This includes growing support for the implementation of information transfer models that better support the general public as a stakeholder. Here, we seek to present an overview of this barrier between science and policy and how it applies to the transfer of aviation research into information that proves useful in the policy making process. We then look at the ways in which visualizations are being used to contribute to the policy making process. The paper concludes with the presentation of a novel method of displaying complex 4D aviation data to non-experts using the well known and intuitive geographical visualization tool, Google Earth.

II. Research Culture

Political opinions that lack a credible supporting argument will not influence policy. Likewise, environmental forecasts based solely on scientific objectives have little chance of contributing to the formation of new regulation [5]. Therefore, there must exist an inextricable link between science and policy; with governmental agencies relying heavily on scientific findings to guide decision making, and research institutes increasingly dependent on government funding. However, there exists a historical divide between scientists and

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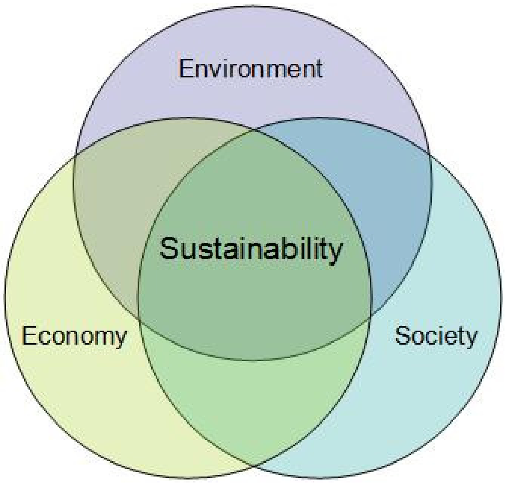

Figure 1. The concept of sustainable development requires a balance between social, economic and environmental factors

policy making communities that hampers the free flow of information from one side to another.

Alcamo [6] pointed out that scientists and decision makers "speak different languages". Price [7] hypothesized that the problem stems from differences in the motivations of the parties involved. On one side of the divide are scientists, motivated by the pursuit of knowledge through thorough investigation. On the other side we find politicians, motivated by electoral support and whose decisions are based on debate, compromise and response to shifts in public opinions. This disparity generates an inevitable conflict. These opinions are echoed by Lee [8], who notes in addition that the differences in cultures, standards and practices of science and politics can lead to distrust. Fischer [9] highlights the "politicization of science", whereby politicians have in the past misinterpreted or misused scientific data to support their own agendas. Because the general public will often take publicized information at face value, this can be interpreted as if the scientists are for or against a particular argument and subsequently affect the reputation and credibility of those involved.

Furthermore, science has historically adhered to the paradigm that research is objective and value free. However, this is rarely the case in reality. Subjective decisions to define a research problem, establish methodologies, choose which models to use, which assumptions to apply, and how results are presented are made at all stages of the research process. Cullen [10] argued that this means science is unable to deliver non-arguable conclusions because personal interpretations are made by scientists all the time. Sundqvist [11] stated that the barrier is perhaps not between science and policy, but established by social constraints where all parties "act strategically by drawing boundaries which suit their own interest". Engel-Cox [4] echoed this thought, stating that the key to using scientific data in policy is the relationship between the scientists and the policy makers who are directly involved in the exchange of information.

Norse [12] notes that the process of policy development itself can create a barrier between scientists and policy makers. He observed that policy development is rarely linear or logical, can take an extremely long time and the end result is not guaranteed to have any scientific rigor. Engel-Cox [4] explains that regardless of the clarity of the presentation, science is never able to overrule political and social considerations. A recent example is the introduction of international agreements on emissions caps. Despite worldwide agreement from the scientific community that human activity is a *"very likely"* cause of accelerated climate change [13], the United States and China continue to oppose the introduction of emissions caps. Such is the frequency of these occurrences, the acronym 'NIMTO' (not in my term of office) has come to being solely to describe policy decisions that go against the grain of logic and/or science in favor of increased electoral support. This additional bureaucracy combined with the risk of negative exposure often represents too great a danger of negative repercussions and prevents active scientific engagement.

Despite this, the need for interdisciplinary collaboration has never been greater. Sustainability and the pursuit of sustainable development are touted with ever-increasing regularity and achieving a sustainable future requires a balance between social, economic and environmental factors (figure 1). If research is to adapt to better transition science-policy divide, it is necessary to understand the needs of each party and how data evolves as it moves through the decision making system.

Norse [12] explained that information that is useful by policy makers will represent a considerable reduction in both size and complexity from the original scientific data. This reduction in volume has the potential to greatly increase subjectivity and increase the likelihood of misinterpretation. This is equally true of the transfer of information to the general public because there will inevitably be components of the original data that are beyond their technical understanding.

A solution would be to ensure that scientific guidance is present throughout the transfer process. Anderson [14] highlights the importance of including a 'broker' to ensure the smooth translation of scientific findings into policy. However, performing such a role requires the ability to understand both the science and the policy making process. Individuals who are both capable and prepared to perform such a role at the highest level are few. Lee [8] refers to them as 'philosopher kings'; a term lifted from Plato's writings on philosophy and political theory where it is stated that, in an ideal society, those in positions of control must have a firm understanding of philosophy; the science of the time. *"…philosophers [must] become kings…or those now called kings [must]…genuinely and adequately philosophize"* [15]. Fischer [9] applied the less elaborate term "movement scientists" to describe those capable of generating meaningful policy from scientific findings.

Environmental research often results in controversial recommendations that invite strong challenges. Bickerstaff [16] speaks of a 'halo effect' whereby the general public refuses to acknowledge the influence of their own activities as they perceive them to be insignificant. They instead place blame on factors they feel they have no control over. Environmental research relating to aviation is particularly susceptible to challenge because it is known that its environmental impact is projected to increase. Aviation is therefore subject to contest from Governments, NGOs, local councils, local residents, the

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general public as well as a host of other industries looking to divert attention.

The problem with providing scientific guidance at all stages therefore stems not from the scarcity of "movement scientists", but that it is not feasible to provide continual expert guidance in most scenarios, especially those that include the public as a stakeholder. Consequently, there is the need for methods of presentation that anticipate the effects of the policy process and are capable of bridging this divide between experts and the lay audience without expert intervention.

There is an increasing number of advocates for the benefits of a "civic science" for environmental research [17,18,19,20]. Civic science is the use of science for policy making through the involvement and understanding of society as a whole. Shannon [20] summarized: "*civic science involves scientists as citizens and citizens as lay scientists in a process in which knowledge production is integrated with and therefore cannot be separated from […] the moral effects of political deliberation and choice*". Social issues are not treated as separate issues but encapsulated in the research at conception. This holistic approach complements the concept of sustainability but means that it becomes essential that information is presented in a format that supports the lay participant.

III. USING VISUALIZATIONS IN POLICY

Visualization techniques are already used in a number of scientific fields to convey complicated data to the non-expert. The best format in which to present research findings will depend entirely on the anticipated audience. Engel-Cox [4] lists five basic formats of visualization: graphical, symbolic, metaphorical, photographic and quantitative.

Graphical visualization refers to the basic graphics one would find in standard reporting. These are obviously essential in a technical context but large, multidimensional data sets pose a number of problems, and their visualizations (in the form of charts, tables, graphs etc...) can end up complex, confusing, and difficult to read.

Symbolic visualizations refer to those that carry particular meanings. This could be as simple as a slogan or logo (e.g. the Fair Trade logo) or even an event (e.g. the 2005 Live 8 event intended as a visual spectacle to encourage support for the Make Poverty History campaign).

Metaphorical visualizations are those that explain one concept in terms of another. This is commonly used by news channels to quantify something a viewer would not normally understand in terms of something that they can relate to (e.g. explaining the number of calculations a computer performs in one second in terms of the number of man hours required to achieve the same result). Metaphorical visualizations also encompass virtualization tools like Google Earth. This tool allows many 'layers' of separate information (satellite images, terrain maps, street and road networks etc...) to be combined into a cohesion that represents the world we live in.

Photographic visualization is the use of real world images and has been used to great effect in cases where the audience may not know anything about a subject or feel that they have no reason to associate with it. Some of the most striking examples of how photographic visualizations have been used to try and influence policy decisions come from NGOs, who commonly use images or short films to make the lay public aware of the importance and severity of their causes which in turn generates public support. If successful, this increasing support creates a motivation for decision makers to take action.

Quantitative visualization describes images that have additional characteristics that represent numerical data, such as contour maps for local air quality or a world map in which the area of a country is linked to oil consumption. Quantitative visualizations allow potentially complicated numerical data to be displayed in context in a format that requires very little understanding of the underlying science.

Perhaps the most obvious field in which visualization has been exploited for several decades is meteorology, where computer graphics have now been routinely used to display weather forecasts for several decades. In this time, graphics intended for a diverse audience have evolved from simple 2D quantitative maps displaying isobars and cloud patterns into complex 3D and animated virtual earth models which combine all 5 forms of visualization into a single, easily understood presentation of a complex, 4D dataset [21].

Environmental fields are also increasingly turning to augmented visualizations to present their findings. One recent application has been in attempting to present the anticipated impacts of global warming. Because the effects of climate change materialize so slowly, most people are unaware that they are happening around them. Furthermore, most are aware that the dramatic effects of climate change will not occur during their lifetime. This can make it difficult to inspire people into taking action. Dockerty [22] proposed a method influencing agricultural policy by presenting photorealistic images of the local landscape that have been modified to show the likely future effects of climate change (e.g. change in vegetation and land use) for various policy scenarios. Visualizations of this type are intended to illustrate the potential implications of different policy decisions on the local environment in an attempt to motivate stakeholders into making decisions that better consider the wider environmental implications. Sheppard [23] commented that there were perhaps several scenarios that warranted the use of visualizations that were specifically extreme enough so as to sway stakeholders into taking action.

However, Lowe [24] has highlighted the potential negative consequences of the exaggeration of negative effects. He found that films like "The Day After Tomorrow", which take scientific theory and exaggerate the consequences for dramatic effect, have the effect of reducing people's belief that such extreme consequences are possible results of climate change. It is therefore essential to ensure that, however simplified visualizations maybe, they retain a firm scientific grounding.

IV. INTERACTIVE VISUALIZATION

So far, we have touched only on methods of presenting findings directly to an audience. Yet, dramatic increases in the graphical capabilities of personal computers have resulted in the increasing use of tools that allow interactive data

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Figure 2. Airport terminal buildings can be rendered in 3 dimensions and color coded according to function

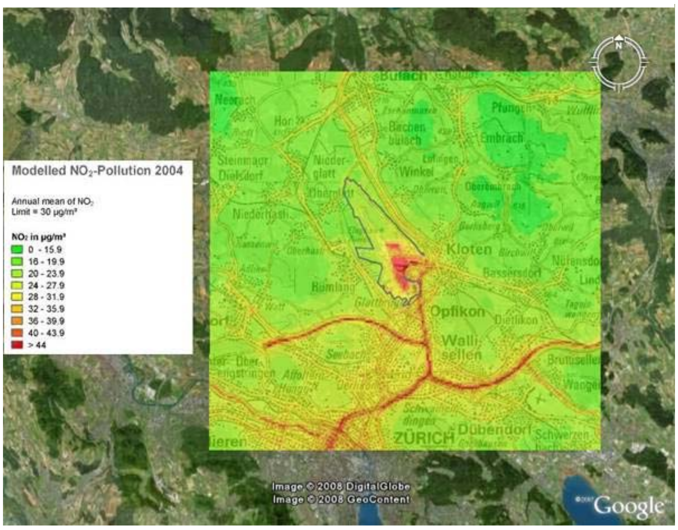

Figure 3. Image overlays can be viewed alongside streamed content. This example shows high NO_x concentrations that align with roadways

Figure 4. Additional information can be embedded into the visualisation. Here, a point marking the location of an air quality sensor contains additional information when clicked

presentation. Haase [21] noted that complex data can be understood much faster if the recipient has control of all spatial dimensions during visualization. There is now a vast range of software packages devoted to the display of 3D and 4D data. They are particularly useful in cases where the data to be visualized is simulated and therefore already stored electronically. A problem does exist though, in that there are many simulation tools and subsequently a large number of bespoke data formats. This means that a lot of data sets can only be visualized using bespoke applications or are tied to expensive, third party package (e.g. ArcGIS). In such cases, the costs associated with acquiring licenses for these packages and the time required to learning how to use them can be significant. This means interactive visualization of such data sets is often limited to experts.

Furthermore, if visualizations are tied to third party applications, the project is bound to the vendor's development schedule. This could introduce unexpected compatibility problems at any time. Similarly, research projects who design and maintain their own 3D and 4D virtualization applications must deploy significant time and specialization. It is therefore not surprising that a number of bespoke applications often lack the functionality of third party alternatives or are simply so constrained by the availability of resources that they fail to keep up with changes in technology.

A possible solution is to integrate software that is either Open Source or freeware. Open Source tools, such as graphics engines, are community maintained and free to use (according to one of several general public licenses). The benefits of using an open source graphics engine is that they offer the developer immediate access to the latest graphical techniques with no personal development required, leaving them the flexibility to focus on integration of the features they need for their own applications. Examples of popular open source graphics engines include ORGE 3D, Genisis3D and jmonkeyengine to name but a few.

Freeware refers to applications that are developed and distributed free of charge. Although using freeware still means a developer has limited control over future functionality, the fact that they are free means that a data set can be viewed by anyone with a sufficiently capable computer.

Which freeware application is appropriate could be a factor of license, application, functionality, support and ease of use; and there are many to choose from. Some of these are developed and maintained by some of the largest organisations in their field. For example, for visualizing data on a global, regional or local scale, one could choose from World Wind (developed and maintained by NASA), ArcGIS Explorer (developed and maintained by ESRI), Virtual Earth (designed and maintained by Microsoft) and Google Earth (developed and maintained by Google), which represent a tiny sample of those available.

Many applications make use of the fact that most people are now web enabled. The internet has long been seen as an ideal environment to publish data where interested parties are able to view data interactively and at their leisure [25]. Many of these visualization applications run within a web browser (e.g. Google Maps and FlashEarth) while large numbers of other

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Figure 5. Files can be made to show data on local, regional and global scales. Here we see an example of trans-Atlantic flight paths from Brussels to Toronto

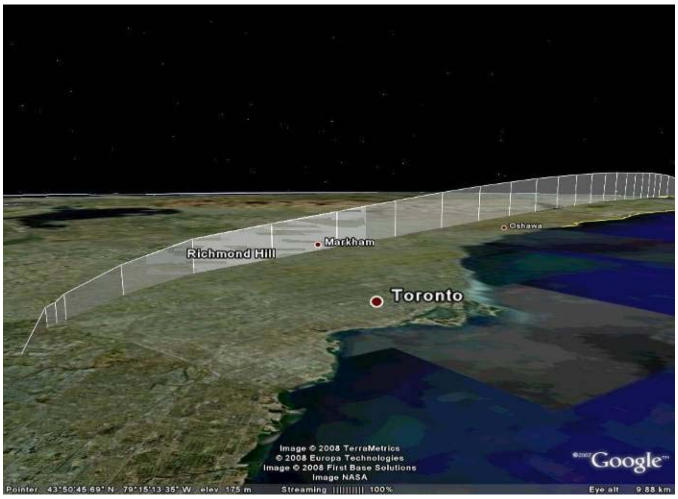

Figure 6. Zooming in and tilting the viewing access allows the profiles to be viewed with altitude and great circle path clearly displayed

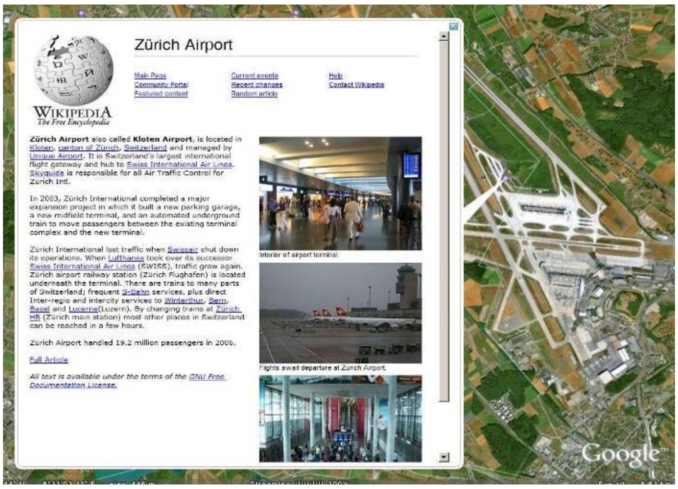

Figure 7. Content can be streamed into the virtual environment from any external server using basic HTML of Network Links. This image shows a viewer calling on additional background information on Zurich Airport from the popular free encyclopaedia 'Wikipedia'

applications establish network links to stream the content being displayed directly from remote servers. There are many benefits from streaming content to a viewer. Initially, the dataset remains under the control of its creator. That is to say, when the dataset is updated on the server, all viewers will immediately able stream the most up-to-date information. A second benefit comes from the fact that streaming content means that the viewing applications themselves can be made into extremely small downloads. This makes the application more accessible as only the most enthusiastic are prepared to wait for a very large application to download.

V. A VISUALIZATION EXAMPLE USING GOOGLE EARTH

Among the many virtualization tools currently available, we consider Google Earth to be particularly suitable for the visualization of aviation data. Presented below is an illustration of how Google Earth could be used to present complex, 4D, aviation research data to a lay audience. The reason for choosing this application over its rivals is that the application is already familiar to millions of users and is used by several prominent media companies (including the BBC and CNN) to display geographical information to a non-expert audience. Google Earth is also being used in many other fields to simplify the visualization process.

A. 4D Content

One of the fundamental problems with presenting paper or electronic reports is that display is constrained to a static 2D presentation. This can make it extremely difficult to present findings that are three-dimensional (e.g. aircraft flight paths) or that are time evolving (e.g. local air quality or noise contours). Virtualization models do not suffer from this limitation.

Google Earth allows user-generated content to be displayed within the virtual environment alongside the huge amount of continuously improving geographical information it streams directly from the Google servers (e.g. satellite imagery, road maps, place names, landmarks). User- generated content is written in a very simple, plain text XML format. Features such as points, lines, areas, volumes, image overlays, pop ups and dynamic, streamed content (e.g. embedded web pages, videos or real time data) are all supported.

A viewer is given full control over the height, direction, viewing angle and perhaps most importantly the time they spend viewing each piece of data. This allows the viewer to move through and around the data set at a speed at which they are comfortable. By adding point markers, lines, areas and volumes to the virtualization, features like sensor locations, roadways, runways, flight paths, buildings, areas of interest etc… can all be added to the data set to achieve a much higher level of understanding of their spatial relevance.

Figure 2 shows a mock-up with a number of main terminal buildings and hangers of Zurich Airport. In this instance, the buildings have been colored so as to differentiate between functions (yellow for terminal buildings, blue for aircraft hangers). The viewer is able to toggle all user-generated feature on and off if they care to reduce the number of obstructions from the view.

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Figure 3 shows how image overlays can be integrated into the view. In this case, a quantitative map indicating simulated NO_x concentrations is presented above Zurich Airport. This is supported by a graphic that is fixed relative to the viewing window which provides a scale for interpretation.

The Google Earth environment is also able to streaming and displaying complex terrain information from the internet. At present, this data is not accessible for use outside of the application (e.g. as shape files for use in emission dispersion models), however it does add an additional component to the model that enhances the user's ability to relate the data presented with the real world.

B. Augmented Visualizations

When presenting data in a paper report, there is only so much information that can be presented within a single graph, image or table before clarity will be lost. In cases where there is a large amount of data to present, this may require several pages to explain a single scenario in sufficient detail.

Using an interactive visualization tool like Google Earth, the same effect can be achieved by augmenting a single basic data set with additional information. The viewer can recall if and when they choose to view this additional information. Figure 4 shows how additional information can be added to the basic, user defined, and geometric additions - in this case a point marker indicating the location of an air quality sensor. Clicking on the marker brings up additional information about the type of receptor, including pictures of the sight and links to published concentration values. Having this information available but displayed only on request allows the virtualization to retain clarity.

Figures 5 and 6 show a number of trans-Atlantic flight paths from Brussels to Toronto. In a paper report, one would be able to do little better than the 2D image shown in figure5. However, the virtualization allows these flight paths to be viewed on a tilted axis, exposing the additional component of height. Furthermore, each flight path can be extended to ground, showing the grand circle path of each route.

Google Earth allows all basic markers to be augmented with formatted text, images, external web links and even embedded videos, either from within the 3D environment or via links added to the side bar. Subsequently, a great deal of information can be contained within a single file that a viewer can explore intuitively in an uncluttered fashion.

C. Network Links

A feature that is of great use in virtual environments (like Google Earth) is the ability to stream content dynamically from remote servers. This allows data to be published and maintained from a single central location, and have that newest data sets automatically feature within the viewers virtual world.

An area where a centralized dataset could provide an immediate contemporary benefit would be in storing airport layouts. Currently, defining the locations of runways, taxiways, gates, service roads and buildings must be done for every new simulation or model. A centralized dataset that is continually improved and/or extended by the community would mean that everyone would have access to the latest airport definitions in XML format. These definitions could also be parsed and used by other applications, such as flight path data.

Perhaps of more interest for many aviation applications is the ability to present information in real time (4D data). Google Earth already offers support for GPS tracking information to be integrated in real time within the virtual environment, and a number of commercial services are already offering support for real time aircraft tracking (e.g. fboweb.com and aeroseek.com). If real time data is not available, users can link their data sets to a timeline that features on the viewers' machine. Using video-like start, stop and pause commands or a slide bar, data sets and the corresponding visualizations are streamed from your remote server, presenting a 4D viewing environment.

A final example of how using the internet connectivity of virtualization tools can be used to improve visualizations is shown in figure 7. The Google Earth environment already provides links to a wide range of additional data sources that will automatically provide the viewer with a host of supplementary data, supporting and background reading, images, 3D buildings and videos. Presenting your data alongside other information sources means that the viewer has the option to support his or her understanding without the bias one would associate with a presentation authored by a single person or organisation. This adds an additional degree of integrity to the findings. The example shows the viewer pulling additional information on Zurich Airport from the popular community encyclopedia 'Wikipedia', although the application itself has an inbuilt web browser allowing access to any online site.

VI. CONCLUSION

This paper has investigated a number of problems that exist in generating and presenting research data capable of providing information that can be useful during the policy generation process. It has been found that there remains a number of barriers between the science and policy communities, and that the complexity of these barriers is continually changing as the general public are increasingly encouraged to participate in the decision-making process.

Having noted some of the causes of these barriers and the effects this can have on interactions between stakeholders, we summarised a few of the problems that face the researcher when presenting complex, multi-dimensional data to non-expert audiences. With an appreciation of how data can change as it moves from one party to another, we further explored the nature of visualizations and how they can be used to present complex data in an intuitive manner to non-experts. It is seen that no single method suits all audiences. However, recent developments in virtualization software allow for several formats to be combined into a single, interactive environment.

Although many virtualization tools exist, Google Earth has been shown to be particularly suitable for the visualization of aviation data because of the simplicity of the data format required, its simple and intuitive interface, its ability to display all data formats (including video), because data can be viewed from local, regional and global scales and the fact that data can be streamed to the viewer from any remote server.

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Although Google Earth is not a replacement for scientific reporting, the paper has presented a number of scenarios within the Google Earth environment that would be extremely difficult and/or time consuming to present with sufficient understanding in a standard document.

In closing, we conclude that changes in the policy-making process facilitate a need for simplified data presentation and that all but the biggest research projects, who can afford to develop bespoke viewing software, would be unwise to overlook the potential of using visualization tools like Google Earth for presenting to a lay audience.

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