CONCEPTUAL DESIGN OF A REGIONAL HYBRID-ELECTRIC TURBOPROP AIRLINER

THE RELATIONSHIP OF AVIATION TO GLOBAL CLIMATE CHANGE: THE DEVELOPMENT OF THE AVIATION INDUSTRY'S MITIGATION MEASURES AND THEIR PRACTICALITY

A Thesis Prospectus
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By
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In recent years, global climate change has become an ever-pressing issue, with 194 of the UN member states signing the Paris Agreement in 2016, vowing to prevent global temperatures from increasing by 2 ℃, with the goal of limiting the increase under 1.5 ℃ (Paris Agreement under the United Nations Framework Convention on Climate Change, 2016, p. 3). This means that emissions must be reduced by almost 45% for these targets to be met. With such a large emphasis on emissions reduction in many parts of the world, aviation has come under increasing scrutiny. According to D. S. Lee et al. (2018), aviation in 2018 was responsible for 2.4% of global CO2 emissions (p. 4). Additionally, the aviation industry was responsible for 2.94 Mt of NOx emissions in 2018 (ICAO, 2022, p. 29).

The technical project and the related STS research topic directly address this important issue. The technical project is a conceptual design exercise of a hybrid-electric regional airliner that will produce less emissions and consume less fuel while traveling the same distance as conventional regional airliners, ultimately helping to reduce the impact of aviation on climate change. This type of innovative aircraft design is one of the many ways in which the current aircraft industry is seeking to address the climate change issue, and so it would prove wise to also investigate and analyze these other methods. Therefore, the STS research project will explore the environmental and societal pressures that climate change presents on the aviation industry, how the industry responds to said pressures. The paper will evaluate the possible effectiveness, along with the possible societal effects of the industry's responses. As shown by the schedule in Figure 1, the technical and STS research projects will be conducted over the Fall 2022 semester and Spring 2023 semester, with the projects being completed at the end of the Spring 2023 semester. The conceptual design will be created under the watch of Professor Jesse R.

Quinlan, an aerospace engineering professor of the Department of Mechanical and Aerospace Engineering at the University of Virginia. Additionally, the technical project and report will be conducted and written by a team of nine people, with the team members being Robert Taylor, Christian Prestegard, Catherine DeScisciolo, Vincent Fimiani, Kyle Hunter, Daniel Lattari, Kazi Nafis, Michael Richwine, Nathan Vu. The STS project will be completed with the advising of Catherine D. Baritaud, an academic lecturer at the University of Virginia's Department of Science, Technology, and Society.

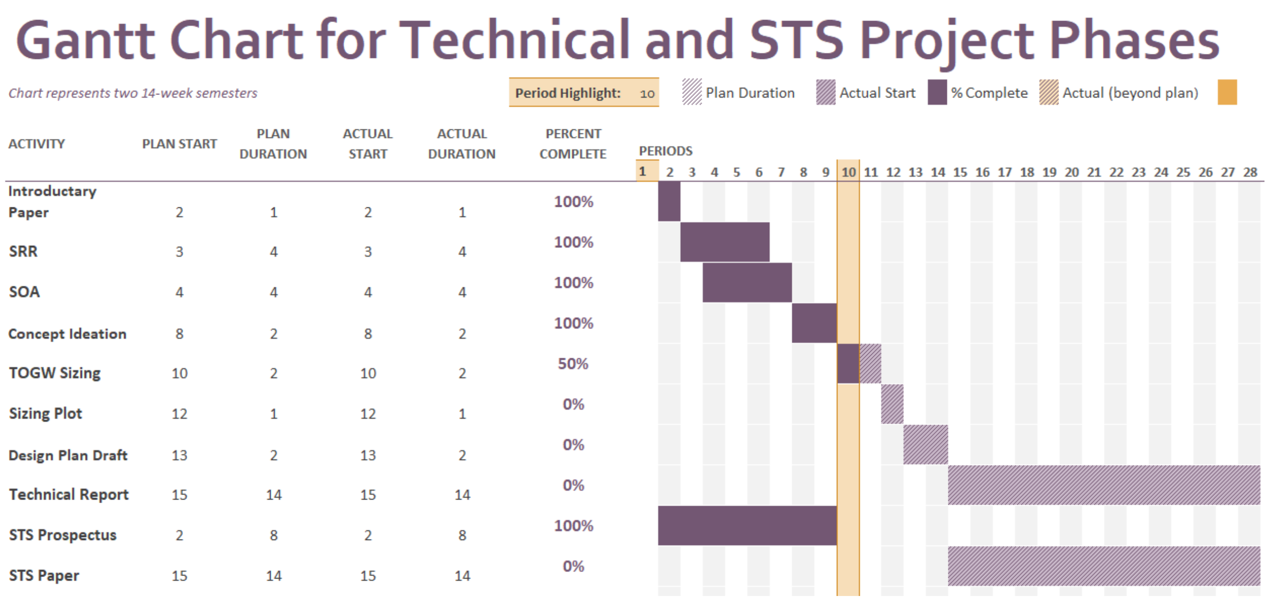

Figure 1: Gantt Chart for Technical and STS Project Phases. The figure shows the general expected and real timelines for each phase of the respective projects. (Hunter, 2022)

CONCEPTUAL DESIGN OF A REGIONAL HYBRID-ELECTRIC TURBOPROP AIRLINER

Currently, there are about 1950 turboprop regional aircraft in service as of 2022, and they provide a vital role in both economy and transportation, with turboprop regional aircraft exclusively relied on by as much as 34% of all airports (ATR, 2022, p. 11), and the market of said aircraft supporting 1.1 million jobs in the US alone (ATR, 2022, p. 12). The in-service number of aircraft, however, is expected to increase to 2660 aircraft by 2041, with almost 2450 of the aircraft being new deliveries. Much of this demand is expected to come from a 35% increase in the number of routes serviced by regional turboprops (ATR, 2022, p. 6). Considering the expected growth in demand for this class of aircraft, it is crucial that next generation of said class of aircraft utilize technologies that mitigate the climate impact of the aviation industry. One such technology is the electric powertrain, where electrical power is utilized somewhere in the aircraft powertrain, in contrast to traditional powertrains which use power generated almost solely by hydrocarbons. This technology crucially promises both benefits in fuel consumption and CO2 and NOx emissions, both of which are significant contributors to the aviation industry's climate impact. This technology has additionally been utilized to great effect in conceptual airliners and demonstrator aircraft such as the NASA PEGASUS, which possessed 27~39% less total energy consumption compared to existing aircraft (Antcliff & Capristan, 2017, p. 13), and the SynergIE turboelectric aircraft concepts, which saw between 4.5% to 8.5% reduction in block fuel consumption (Biser et al, 2020, p.23).

Therefore, this technical project will have the objective of creating a conceptual design of a hybrid-electric turboprop regional airliner following the requirements laid out by the Hybrid-electric Regional Turboprop RFP created for the American Institute of Aeronautics and Astronautics (AIAA) Undergraduate Design Competition. In general, the RFP seeks an aircraft that is "at least 20% better than existing 50 seat regional turboprops in 500 nmi block fuel per seat with a cost to build that is comparable to the existing aircraft, including the hybrid propulsion system" (AIAA, 2022, p.1), with an entry into service date of 2035. The conceptual aircraft that will created in this technical report will ultimately serve as a model for future environmentally friendly regional turboprops.

As shown by Figure 2, the initial requirements analysis, research, concept definition, and sizing will be done in the Fall semester, consisting of seven phases: an introductory paper, a Systems Requirements Review (SRR), State-of-the-Art Reports (SOA), concept ideation, creation of a take-off gross weight (TOGW) sizing algorithm, creation of matching and carpet plots based on the sizing algorithm, and an initial design plan draft to be created at the end of the Fall semester.

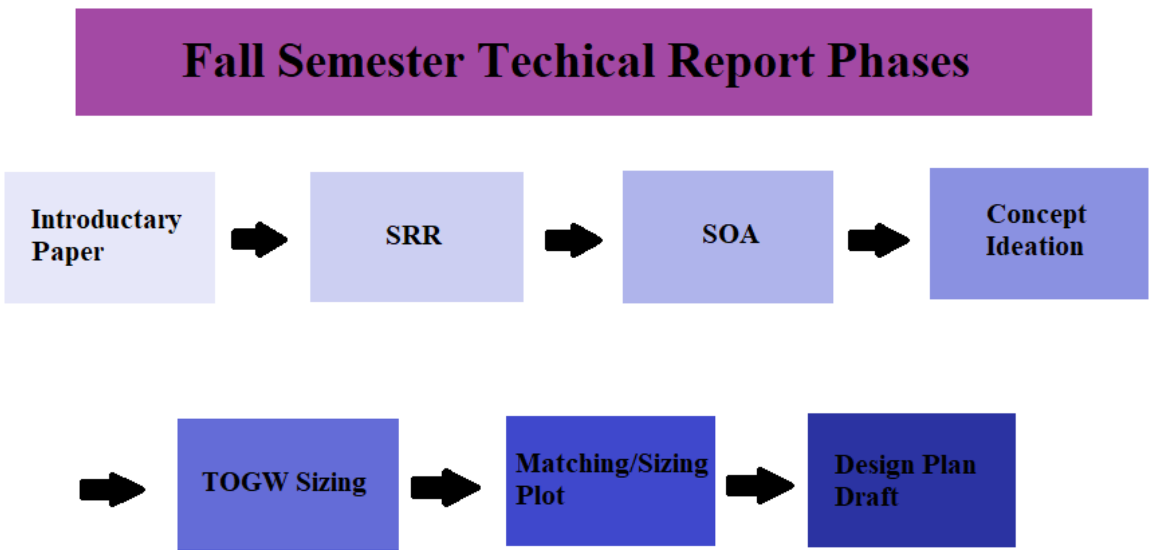

Figure 2: Fall Semester Technical Project Phases: Visual of the phases of the technical project that will be undertaken in the fall semester. (Hunter, 2022)

The introductory paper serves as an initial research report to familiarize oneself with the fields of regional turboprop aircraft and electric powertrains. The SRR serves as an analysis of the RFP requirements, highlighting which requirements will be most crucial in the creation of the aircraft concept. The SOA report serves as useful amalgamation of information regarding crucial technologies and processes, such as distributed electric propulsions and aircraft lifecycle analysis. The concept ideation exercise serves as a structured brainstorming session, where based on the SRR and SOA reports, a series of nine basic concepts are created that will best satisfy the requirements. Out of the nine, three are selected for further analysis and refinement. As shown by Figure 3, the concepts at this stage are still very basic, being mostly just representations of potentially useful design features and configurations. Then, based on the selected configurations, TOGW sizing algorithms will be created in MATLAB to calculate the general weights of the aircraft concepts. Using the weights calculated by the algorithms, a series of carpet/matching plots will be created to determine the projected and needed performance of the concepts. Finally, an initial design plan draft will be created based on the previously mentioned studies that will serve as a framework for the final report that will be worked on throughout the spring semester.

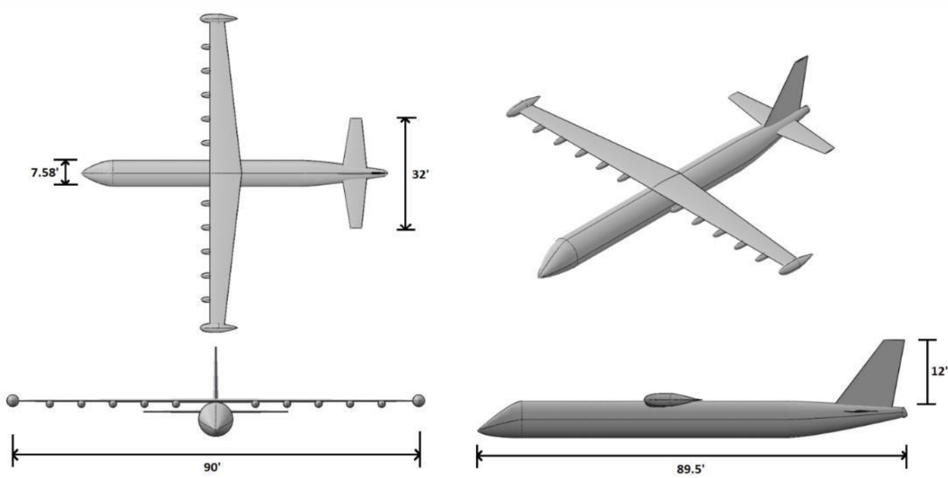

Figure 3: Concept Ideation Example: An example of showing the type of concepts laid out in the concept ideation phase of the project. (Hunter, 2022)

THE RELATIONSHIP OF AVIATION TO GLOBAL CLIMATE CHANGE: THE DEVELOPMENT OF THE AVIATION INDUSTRY'S MITIGATION MEASURES AND THEIR PRACTICALITY

With the emissions generated by aircraft having a clear global impact, there has been a tremendous increase in pressure on the aviation industry to mitigate its existing impact. This has been seen on both a business and governmental level, with groups representing aviation business such as General Aviation Manufacturers Association (GAMA) and National Business Aviation Administration (NBAA) committing to decarbonization by 2050 (ICAO, 2022, p. 106), and the inter-governmental International Civil Aviation Organization (ICAO) setting a target of carbon neutral growth from 2020 onwards (ICAO, 2022, p. 83).

All this combined pressure from industry and governmental stakeholders has had the effect of freeing up more available resources for research into both technological and operational innovations that may serve to mitigate the aviation industry's overall emissions, such as the White House's recent investment of 4.5 billion dollars into sustainable aviation fuels (The White House, 2021). Using, the newly available resources, the aviation industry and its engineers have begun programs and engineering programs with said goal, such as the Europe launching the Clean Sky 2 development program with the goal of reducing CO2 and NOx emissions by 20 to 30 percent (Clean Aviation Joint Undertaking, 2021, p. 17), and NASA including goals of CO2 and NOx emissions reductions of 10 to 15 percent by the 2035 period in their newest Strategic Implementation Plan (NASA ARMD, 2019, p. 40).

However, while this general description of the current stakeholders and their effects on the industry and its engineers due to climate change paints a positive perspective of the development of mitigation technologies and operations, similar pressures and resources in the past have been allocated in past crises that have failed to materialize technological solutions, a good example of this being the Advanced Turboprop (ATP).

THE NEED FOR GOOD FEEDBACK AND COMMUNICATION BETWEEN STAKEHOLDERS AND ENGINEERS

The ATP, also known as the Unducted Fan (UDF) is one of the new mitigation technologies being pursued in current efforts, due to its higher efficiency and lower fuel consumption compared to traditional aircraft engines. However, it was also pursued in the 1980s under NASA but failed to develop and be diffused across the industry at that time (Kajikawa et al, 2012, p. 92). This was even though the technology had a large amount of governmental and business stakeholders, due to the coinciding oil shocks of 1973 and 1979 making such a technology extremely attractive in the aviation landscape at the time, and the technology was made a top research priority (Kajikawa et al, 2012, p. 94). However, the technology was hampered by a variety of issues such as noise (passenger discomfort and regulations), fatigue, safety (excessive vibration) (Kajikawa et al, 2012, p. 94), and reluctance of airlines to adopt the technology due to risk (Kajikawa et al, 2012, p. 98). This delayed the development of the technology until the opportunity window of the period of high oil costs ended, which caused the impetus to develop a technology seen as riskier and maintenance intensive to disappear, causing the technology to lay dormant until now, where similar pressures have again reappeared.

While current engineers working on such technologies need not worry about an opportunity window closing (as climate change is not a temporary issue), the ATP example shows that they will need to factor in the potential risks of new technologies and communicate and receive feedback from stakeholders such as airlines, passengers, and regulatory bodies on the risks and tradeoffs of new mitigation technologies to allow timely development of said technologies. This type of approach is best embodied by the study done by Capurro et al. (2015) regarding sustainable biofuels, a technology very similar to sustainable aviation fuel, where public values regarding sustainable biofuels, such as how the public views the technology's risks and benefits were polled to better understand what drives said public values (p. 1). This type of feedback and communication will ultimately allow industry engineers to develop mitigation measures that are practical for the end users, allowing them to succeed in development where past efforts failed.

APPLCATION OF THE SOCIAL CONTRSUCTION OF TECHNOLOGY FRAMEWORK TO DETERMINE PRACTICALITY

This interaction between passengers, airlines, regulators, governments, etc. with industry and engineers, with both positive and negative relationships can be illustrated through the Social

Construction of Technology (SCOT) model as seen in Figure 4. This framework, developed by William Bjiker and Trevor Pinch in 1984, shows the mutual relationship between various social groups and the engineers at the center of the relationship influence the development of technology. The engineers, when developing the mitigation measures must carefully balance the feedback and requirements from airlines, airports, governments, industry groups, manufacturers, and passengers, and negotiate between said groups to enable the development of a practical

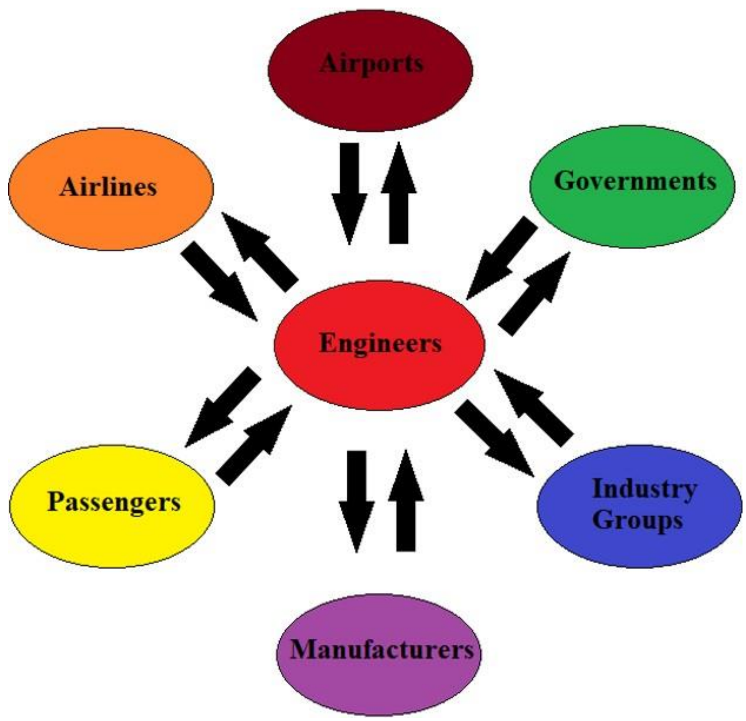

Figure 4: SCOT Model for Mitigation Measures: Engineers developing mitigation technologies must balance and negotiate demands from at least six different groups. (Adapted by Hunter (2022) from Carlson, 2009)

mitigation measure in a timely manner. For example, if one was to apply this model to the mitigation measure of the blended- wing-body (BWB) configuration, which is currently being studied to reduce CO2 emissions by almost 50% (Reim, 2020), as shown in Figure 5, the requirements and impetus of the design to the engineers would be from the emissions reduction goals mentioned beforehand from both government and industry groups, but they would also receive feedback from passengers about the discomfort of the largely windowless seating arrangement (Chen et al, 2019, p. 1800), feedback from airports about the difficulty of accommodating an aircraft using a novel configuration in existing airport infrastructure (Chen et al, 2019, p. 1800), feedback from airlines about the difficulty of maintaining said configuration (Chen et al, 2019, p. 1800), and feedback from manufactures about the potential risks of producing a completely novel aircraft configuration. Engineers working on this technology must negotiate between the conflicting requirements (such as comfort versus superior emissions performance) to make sure the mitigation measure is ultimately practical and likely to be adopted.

So, to determine the possible practicality of a mitigation measure, one can analyze how well the mitigation measure can meet the requirements given by the various groups, how flexible said groups are to possibly changing their requirements according to feedback from the engineers working on the measure, and how well the engineers can negotiate between the requirements and needs of the different groups influencing the development of the measure. By seeing how each analyzed measure compares to others in these qualities of the SCOT model, one can determine how practical and implementable each measure may be, allowing for possible prioritization of measures that have a high chance of success. Additionally, thanks to the visualization of the relationships between technology and society by the SCOT model, one can easily identify where in the network there is an issue that may be holding back the development of a measure. This can all be used as useful information and feedback by the aviation industry when developing their mitigation measures.

Therefore, the STS paper will be in the form of a scholarly article that will explore the relationship between social and technical groups that due to climate change influence the development of climate impact mitigation measures and the engineers in the aviation industry that develop said mitigation measures using SCOT frameworks for specific technologies. It will determine that practically of said technologies by analyzing the ability of the engineers to balance and negotiate between said groups that influence the engineers and the technology they work on. If certain technologies are shown to have issues in their practicality stemming from issues in the construction of their framework, the paper will suggest possible improvements to the social-technical network that influences said technology to better its development.

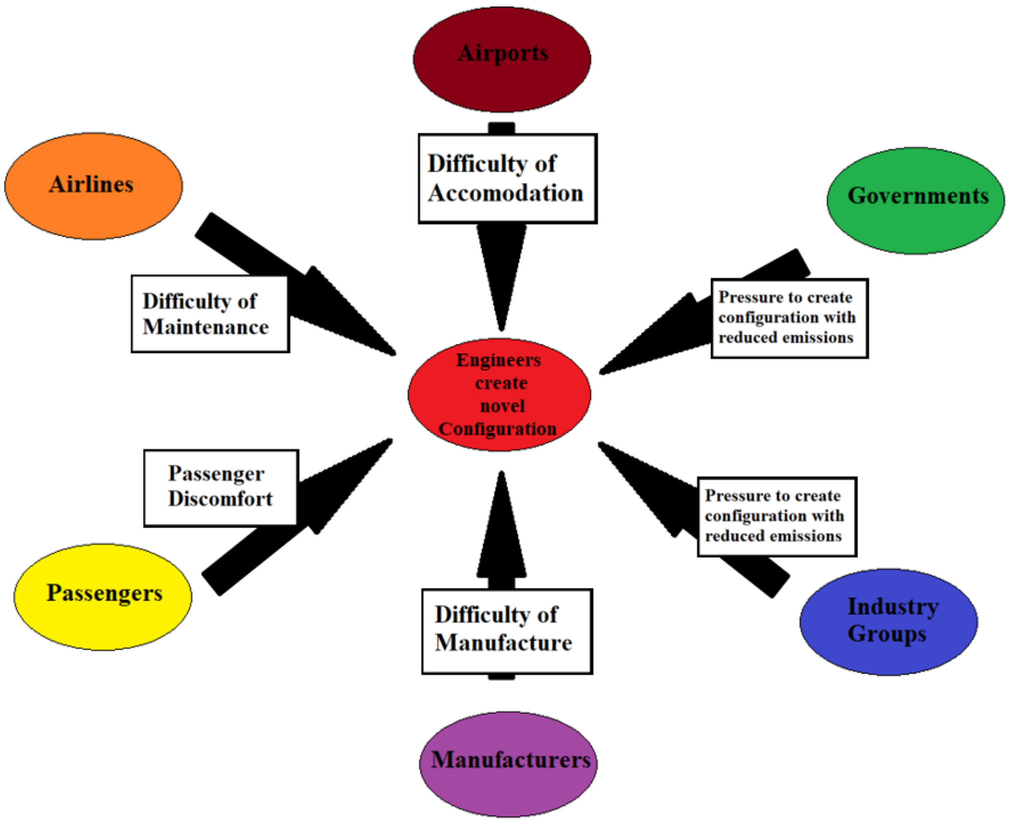

Figure 5: SCOT Example for BWB: Engineers, during the development of mitigation measures, often must balance between conflicting feedback from social groups as shown here. This is often done by giving their own feedback back to the social groups to negotiate (Adapted by Hunter (2022) from Carlson, 2009)

ADDRESSING AVIATION'S CLIMATE IMPACT

Climate change is an increasingly growing serious threat to humanity, as the environmental changes brought on by the changing climate will potentially have devasting effects on human populations, the economy, and living conditions. To properly address this threat, existing human industry that exacerbates the effects of climatic change must be adapted in a manner that slows down or completely stops their contribution to climate change, with the aviation industry being one such case. Therefore, it is important for the aviation industry to have effective mitigation measures in place to reduce its impact.

Thereby, by directly analyzing and creating a conceptual aircraft concept based on one type of mitigation measure and analyzing other possible measures through a socio-technical framework, a deep analysis of both how aviation industry developments are impacted by climate change, and how said developments seek to address said change can be conducted. Based on this analysis, one can conclude if the measures practical in their ability to be implemented, and if not, possible technical and social solutions to issues that are reducing the practicality of certain measures and developments. This information can then be used by the industry to bring about more effective measures or improve current measures to improve the industry’s overall climate impact mitigation.

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