Cold Gas Dynamic Spraying Integration Complexity

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Abstract: - Studies show that aerospace products operate in very aggressive environments characterized by high temperature, high pressure, large stresses on individual components, the presence of oxidizing and corroding atmosphere, as well as internally created or externally ingested particulate materials that induce erosion and impact damage. Consequently, during operation, the materials of individual components degrade. In addition, the impact of maintenance costs for both civil and military aircraft was estimated at least two to three times greater than initial purchase values, and this trend is expected to increase. As a result, for viable product realisation and maintenance, a spectrum of issues regarding novel processing technologies, innovation of new materials, performance, costs, and environmental impact must constantly be addressed. One of these technologies, namely the cold-gas dynamic-spray process has enabled a broad range of coatings and applications, including many that have not been previously possible or commercially practical, hence its potential for new aerospace applications. Therefore, the purpose of this paper is to summarise the state of the art of this technology alongside its theoretical and experimental studies, and explore how the cold-gas dynamic-spray process could be integrated within a framework that finally could lead to more efficient aircraft maintenance. Based on the paper's qualitative findings supported by authorities, evidence, and logic essentially it is argued that the cold-gas dynamic-spray manufacturing process should not be viewed in isolation, but should be viewed as a component of a broad framework that finally leads to more efficient aerospace operations.

Key-Words: - Technology, Aerospace, Cold spray, Maintenance, Recycle.

1 Introduction

Aircraft maintenance has become increasingly a topic of study with the rise of aircraft fleets worldwide and the lack of financial resources to purchase new aircraft. While there is no unified agreement as to how to define the age of an aircraft, some authorities have set limits on the age of the aircraft, the number of flight cycles, and the number of engine hours, while others have set limits on the number of previous owners amongst other limiting factors such as age-related effects of corrosion [1]. For example, it was estimated that the average age of the passenger carrier fleets is approximately seven years, the average age of their cargo counter parts is approximately twenty eight years [2], and the impact of maintenance costs for both civil and military aircraft is at least two to three times greater than initial purchase values, and this trend is expected to increase [3]. In addition, there is a decreased ability to repair or replace failed components for older aircraft and their components. Reasons for this include, in no particular order, the lack of availability of replacement parts, a decrease in support available from the original manufacturers with some of them no longer in business, and even problems caused by aspects such as outdated technology.

In this respect, there are many engineering approaches to solve the need for new aerospace materials and technologies that constantly address issues such as viable product realisation and maintenance, performance, costs, and environmental impact concerns. However, there are still many shortcomings affecting the implementation and integration of these achievements within the aerospace operations.

Subsequently, section 2 critically reviews a number of aerospace materials and technologies issues, formulates their problems, research gaps, and constructs the research question. Section 3 presents the methodology. Then, in section 4, hypotheses are advanced and, based on the existing body of knowledge, the paper answers these hypotheses. Finally, section 5 draws conclusions about the
hypotheses and highlights its theoretical and practical implications.

2 Problem Formulation
Development of new materials and technologies has followed a number of different pathways, depending on both the nature of the problem being pursued and the means of investigation. Breakthroughs in the discovery of new materials and technologies have ranged from pure serendipity, to trial-and-error approaches, to design by analogy to existing systems. These methodologies will remain important in the development of materials but as the challenges and requirements for new aerospace materials and maintenance operations become more complex, the need to design and develop new materials and develop new manufacturing and maintenance processes will become increasingly important.

One of the technologies which followed the above breakthroughs in new discoveries is the cold gas dynamic spray, often referred to as simply cold spray (CS) process. The phenomenon of CS was discovered in the early 1980s at the Institute of Theoretical and Applied Mechanics of the Siberian Branch of the Russian Academy of Sciences (ITAM of RAS) while studying models subjected to a supersonic two-phase flow (gas + solid particles) in a wind tunnel [4].

CS is a process of applying coatings by exposing a metallic or dielectric substrate to a high velocity (300-1200 m/s) jet of small (5-50 µm) particles accelerated by a supersonic jet of compressed gas. Gas temperature is always lower than the melting point of the particle's material, so, upon impact with the substrate, these high-velocity 'cold' particles plastically deform and bond with the underlying material resulting in coating formation from particle in the solid state. It is this solid state which differentiates CS from the thermal spraying processes which still lack full control of the coating's chemical and microstructural composition due to the particle heating in the reactive combustion gases. At the same time, the new emerging CS process, presents many advantages such as very dense, hard, wear resistant, and corrosion resistant coatings, with minimum oxidation and phase transformations of coatings. As surface protection is expected tremendously to increase its share in future, CS advantages make it a rapidly emerging industrial coatings technology and a first world technology.

However, there are many frontiers CS R&D has to conquer, with one of them being the costs reduction associated with the process. In addition to these CS frontiers which will not be discussed in the present paper, there are increasing demands in aerospace industry with respect to:

- components and life-time systems,
- increased efficiencies, as well as for
- environmental and health protection.

Consequently, with improved CS coating technology and increasing demands with respect to its use in aerospace industry, this paper explores the following

Research Question: Are there relationships between CS development and various manufacturing issues so, by their consideration, could CS process be integrated within a framework that finally could lead to more efficient aircraft operations?

3 Methodology
The scientific method starts when you ask a question about a problem that you have observed and ends with a solution to the problem, so it forms a cycle (Fig. 1).

To find answers to the research problem and sub-problems, a number of specific hypotheses are used in order to gather data and so, satisfactorily solve the research problem.

The term hypothesis derives from the Greek 'hypotithenai' meaning 'to put under' or 'to suppose'. Therefore, a hypothesis is a preliminary or tentative explanation for an observable phenomenon of what the researcher considers the outcome of an investigation will be. A hypothesis could be true or false.

In order for the scientific method to answer the research question, it must be about something that you can measure, preferably with a number. However, because of the manufacturing's research lack of mathematical models, this paper answers hypotheses and research question using support from authorities (research literature published by reputable international journals), evidence, or logic.
Methodology approach

4 Problem Solution

This section constructs the hypothesis and answers it by using support from authorities (research literature published by reputable international journals), evidence, or logic.

Hypothesis 1: Aircraft operations that consider and integrate manufacturing concepts will lead to more efficient aircraft operations.

In Latin 'concipere' means to conceive. So, a concept is considered a general notion or idea derived from specific instances or occurrences that bring diverse elements into basic relationship. Also, a concept is a statement of an idea expressing how something might be done or accomplished that may lead to an accepted procedure [5]. Furthermore, talking about concepts, Einstein said he had always believed that the invention of scientific concepts and the building of theories upon them was one of the great creative properties of the human mind [6].

There are many engineering concepts and they have many shortcomings that affect their implementation and integration within the aerospace operations. Please, note that due to space constraints, every effort has been directed towards minimising the critical review dedicated to each concept. Also, it is presumed that the reader is familiar with some of these concepts. Therefore, a review of the manufacturing concepts shows that:

- concurrent engineering minimizes the product design development and delivery time [7], improves quality and decreasing costs [8], and improves coordination [7],
- group technology reduces setup times, lowers work in progress and inventory, and achieves a smooth overall operation of the system,
- modularity provides a responsive manufacturing system through flexibility/agility within product and process [9], lowers application development and maintenance costs [7], and meets efficiently a broad range of customer requirements,
- flexibility copes with changing circumstances in the manufacturing system [10], and includes, in a rational way [9], a modular product realisation process, and modular-based working practices,
- 'just in time' concept eliminates waste such as excess inventory in all business activities, and reduces lead times in manufacturing and purchasing by applying group technology principles,
- lean manufacturing eliminates the complexity [11] and waste defined as anything other than the minimum amount of equipment, materials, labour, energy, defects, and time that are essential to add value to the product [12],
- virtual manufacturing, an extension of the concurrent engineering strategy, brings companies together to share costs, core skills, and jointly serve one or more markets.

Consequently, in analysing the above, one can see that each concept is intended to create a better, more efficient aerospace operation within an economical context. In addition, considering the relationships between the various concepts, Figure 2 is purposed to highlight the new dimensions of the definition of the agile aerospace operations paradigm.

The model takes into account the characteristics of the market, infrastructure, technologies, and strategies. The justification for this approach includes justifications such as [14]:

- agility without cost effectiveness is not a real competitive strategy,
- the implications of technology in achieving agility are paramount,
- for certain businesses, such as aerospace operations, one needs to identify and apply a set of technologies that are important to the selected market segment, specific products, and their service requirements,
- agile aerospace manufacturing/service requires multidisciplinary skills, and
lack of focus on integrating core competencies would not improve productivity and quality.

Therefore, the following subsections will focus on the above issues by considering the CS process and its integration within more efficient aircraft operations.

However, before this, short definitions of the terms opportunity, bottleneck, and challenge should be considered:

- **opportunity** - a favourable or advantageous circumstance or combination of circumstances, a chance for progress,
- **bottleneck** - something that holds up progress
- **challenge** - a test of one's ability or resources in a demanding but stimulating undertaking.

### 4.1 Markets

With 21,494 commercial aircraft in service in 2011, the Maintenance, Repair and Overhaul (MRO) market was worth $50.2bn. There is increase in the global demand for aircraft MRO with smaller airlines and operators with ageing fleets who lack capital to purchase new aircraft [15].

In this context, the International Air Transport Association (IATA) highlighted the importance of the aviation industry to the economy of South Africa and for the economies of all states in Southern Africa. In 2010, aviation directly contributed 2.1% to South Africa's GDP (ZAR 51 billion), employed 227,000 people, and 21 million people and 240,000 tonnes of freight travelled to, from and within South Africa [16]. Defence sales were the most lucrative in the South African aerospace & defence market in 2009, with total sales of $1.7 billion, equivalent to 68.1% of the market's overall value [17].

Also, IATA outlined four elements for strengthening the foundations of a sustainable aviation industry: improving safety and security, providing cost-efficient infrastructure, and furthering environmental responsibility. With the continent's safety record 12 times worse than the global average, safety has been considered the top priority and Africa's biggest challenge. In addition, with aviation being responsible for 2% of global man made carbon emissions, aviation's ambitious commitments to improve fuel efficiency by 1.5% annually until 2020, and cut net emissions in half by 2050 compared to 2005, must be implemented.

Therefore, considering the market opportunities presented above, there is a need for advanced aerospace materials and new manufacturing processes with increased capabilities.

### 4.2 Technology

For viable product realisation in the market place, a spectrum of issues regarding performance, cost, and environmental impact must constantly be addressed. Novel processing technologies, as well as the innovation of new materials, provide opportunities for product development, improvements in product performance, reduction in costs, and minimising of environmental impact through the complete lifecycle [18].

One of these technologies is the cold spraying process that has the opportunity to improve the aerospace materials R&D and demonstrate its value to the aerospace community. Some of the identified challenges to the growth of CS technology in the aerospace operations include technology and cultural aspects (discussed in section 'Strategy').

For example, CS enables a broad range of coatings and applications, including many that have not been previously possible or commercially practical. Most metals such as Cu, Al, Ni, and Ti, Ni-based alloys, cermets, and ceramics have been deposited by CS [19]. Also, CS has been demonstrated to be a viable and cost effective repair process for the remediation of an otherwise unserviceable component critical to the aerospace operations such as aluminium and magnesium components [20]. At the same time, the key for successes in CS are high impact velocities by high power facilities and new nozzles [21] which finally will extend the range of materials to those with high strength, which require higher impact velocities. Also, the global powder manufacturing community is in the process of adapting the increasingly challenging product requirements related to higher purity, narrower particle size fraction, and controlled particle morphologies [22].

However, the major concerns related to the CS process are equipment availability, affordability, and portability compared with coating methods currently employed.

### 4.3 Infrastructure

It is important to recognize that today's requirements represent a challenge to our current infrastructure [23]. Infrastructure involves far more than the identification of research priorities followed by targeted funding. A combined approach to research that will likely help to ensure a healthy aerospace infrastructure include:
Fig. 2 Agile aerospace operations

- integration of research and teaching with a clear understanding of the market's well-defined need for aerospace materials developed in the university laboratory,
- broadened participation of various areas with research on aerospace materials becoming increasingly interdisciplinary,
- improved infrastructure for research and education with an increased industrial and government investment,
- demonstrated value of research and return of investment to society, and the
- effects of university/industry research for an increased aerospace competitiveness and sector growth.

Basic research, applied research, development, and demonstration play a role at all levels in the process since there is a tight feedback loop between discovery and end use. Continued academic/industrial consortia are expected to strengthen this feedback.

4.4 Strategy

For viable It is necessary to understand how technological advances and scientific breakthroughs relate to society in a global context. Social factors are affected by, and determine the rate of technology adoption. Therefore, for a country to compete in this global scientific marketplace, its technological developments must be increasingly efficient. However, in our market-driven economy, decisions about technology will often be made based on cost and benefit that requires a short time between commercialization and payback.

A strong competitive advantage in materials development that will shorter development time, reduce cost, and bring higher quality and functionality to the final product can be gained if there is an efficient iteration between academic research and industry. The greater the ability of the product development team members to appreciate and/or operate across a variety of scientific disciplines, the better the outcome will be. In this respect, CS offers a perfect example where new coatings could offer many diverse opportunities with niche aerospace material applications that could leverage the unique strengths of CS technology, rather than chase broad market applications.

5 Conclusion and Implications

This paper showed that it is both theoretically and practically possible to find relationships between CS development and various manufacturing and aerospace operations issues.

Based on the paper's qualitative findings, the research problem can now receive a concise answer. Essentially, it is argued that the cold-gas dynamic-spray manufacturing process should not be viewed in isolation, but should be viewed as a component of a broad framework that finally leads to more efficient aerospace operations. For
example, in order to be agile, the framework should take into account the characteristics of the market, infrastructure, technologies, and strategies. Also, this leads to the conclusion that lack of focus on integrating core competencies, including CS process and its associated multidisciplinary skills required, would have a negative effect on productivity and quality of aerospace operations.

Finally, it could be concluded that, in order to address the challenges of cost, performance and environmental constraints, aerospace materials and their associated design and manufacturing processes, including CS, must be optimized in an integrated manner.

References: