Precision Deburring of Aerospace turbine Blades: A Case Study in Success

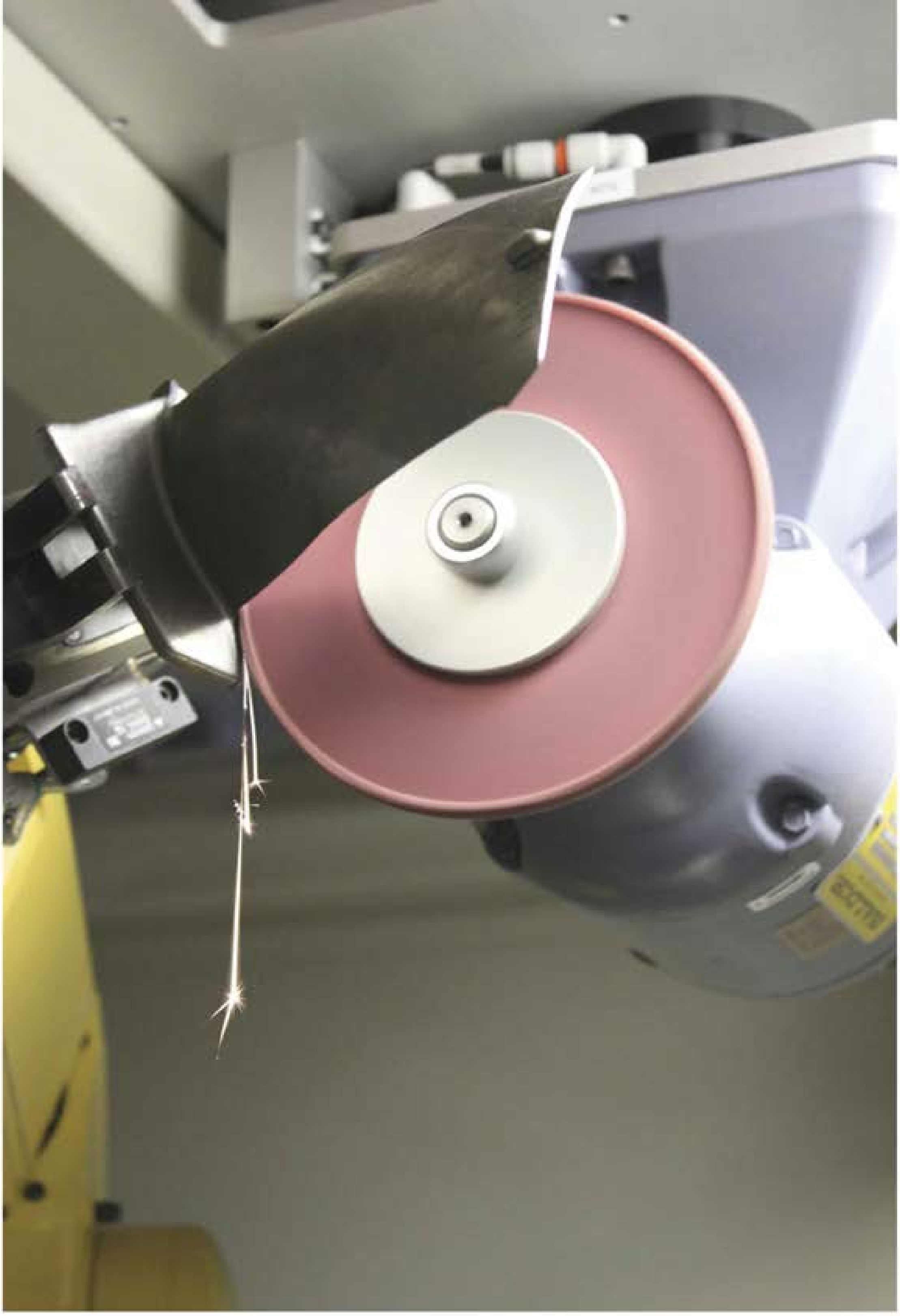
AV&R AEROSPACE:

Canadian firm AV&R Aerospace needed to refine their precision application of robotic deburring of aerospace turbine blades. Known as profiling, a precise edge is needed on the blades to control airflow while increasing efficiency and fuel economy in aircraft engines. When the blades are first cut, there are sharp edges and square angles that need to be profiled to very exact tolerances. The first generation of blades supported by AV&R Aerospace needed a tolerance of 100 microns. This tolerance continued to shrink, dropping to 37.5 microns in the second-generation blade, and falling as low as 12.5 microns in the current generation.

To achieve such demanding specifications, AV&R Aerospace tested many types of abrasive wheels. Non-woven nylon convolute wheels simply could not achieve the required tolerance consistently. But the firm found that the Smooth Touch wheel, from Rex-Cut, was able to hit the 12.5 micron mark in a very repeatable fashion.

Rex-Cut wheels are crafted from non-woven cotton fiber that's denser than non-woven nylon. Cotton fiber mounted points have a cushion action while in use, and due to their density, will hold up well grinding on an edge. Rex-Cut wheels can be used with precision without changing the geometry of the part.

Non-woven cotton wheels feature a consistent finish throughout the life of the wheel, and there is no backing that can gouge the surface of the material. In fact AV&R Aerospace discovered that Rex-Cut wheels lasted ten times as long as other products.



Smooth Touch Medium wheel on an AV&R Aerospace Robotic Finishing System.

REX-CUT WHEELS ADD THE HUMAN TOUCH:

When AV&R Aerospace helped their clients move from human deburring to robotic operations, they had to meet the needs of very demanding inspectors. There was a very specific process, known as Tri-blending, where abrasive wheels were needed to join three different surfaces. The inspectors were used to very specific results achieved by human operators, and AV&R Aerospace knew they needed to replicate these results if they were to be successful.

The firm once again tested multiple abrasive wheels, but only Rex-Cut wheel achieved the same results as a human operator when deployed in a robotic application. The Rex-Cut Smooth Touch wheels, using cotton's inherently natural mechanical strength, combined with laminated layers of abrasive, were able to hold up under the high-stress environment and "fool" the inspectors.

Normand Stoycheff, Support Manager with AV&R Aerospace, highlighted one other important value of working with Rex-Cut. "We work in a high technology environment," he explained. "Every time we have a new order for a new part that is to be crafted manually, if I need help, I would call Rex-Cut and they would create the custom abrasive that I needed. This is something that I really appreciate from this company compared to other larger firms. Because we're small, so it's hard to gain the understanding of the big companies—they're simply not listening to us. With Rex-Cut, I tell them my process and they suggest a solution. They even created the Smooth Touch high-density abrasive especially for us. It's that level of service that really makes the difference."

Rex-Cut delivers predictable precision for roughly the same price as other abrasive products. When you consider a wheel that lasts ten times as long, and can achieve a tolerance less than 15 microns, the superiority of this wheel is self-evident. Whether used in robotic applications or with human operators, Rex-Cut wheels are the natural choice.

January 2015 - http://info.rexcut.com/blog/

©NasmythGroup

SUPPLYING THRUST FOR THE FUTURE

Ed Hill discovers how automation and new materials are changing the production landscape for aero engines from two leading practitioners.

ABOVE: A Mazak 5-axis robotic machining cell

Aero engine designers and manufacturers face a number of challenges when it comes to supplying the latest components. There is the constant demand from OEMs and airlines to produce more fuel efficient, reliable engines, ever tightening environmental initiatives, such as Clean Sky 2 to reduce noise and pollution emissions and added to this predicted ramp up rates, particularly in the civil sector, meaning more rapid methods of production are required throughout the supply chain.

François Arrien is vice-president for business development at Canadian robotic finishing specialist AV&R Aerospace. The company is a leading developer of automated technology designed to increase the production of turbine blades/vanes in aero engines.

He believes there are still areas where engine design can achieve efficiencies but new manufacturing technologies will have to be implemented to achieve them.

"Increasing fuel burn efficiency allows a significant reduction of CO_2 and NOx emissions and represents tremendous fuel savings for airlines. One of the main methods to achieve this goal is to improve aerodynamics on compressor blades and vanes by using more complex 3D shapes and tighter tolerances on leading and trailing elliptical edges. Tolerances on newer engines are around 37μm and are planned to go to 25μm. With these new requirements manual profiling is no longer sustainable. Aspects such as labour costs reduction, difficulty to find skilled operators and eliminating injuries also point to automating this operation."

Peter Smith CEO and chairman of the UK's Nasmyth Group, which produces many parts for the aerospace industry, believes longer term more radical design solutions may be required.

"Clean Sky and new developments in Clean Sky 2 appear to be hitting the mark and delivering results on Low Pressure Ratio Fan/Variable area fan nozzles, Low Weight/Low Drag fixed or rotating

structures, nacelles and high power gearbox. If we are focusing on reducing CO_2, NOx and noise emissions then we should be working on hybrid engines, if not 100% electrically powered."

Metal matters

Leaner and consequently hotter engines of the future will demand new sophisticated heat resistant super alloys (HRSA) with new machining challenges. Smith is also conscious that costs will be a major consideration.

"HRSA fall into three groups, nickel-based, iron-based and cobalt-based. The physical properties and machining behaviour of each varies considerably, due both to the chemical nature of the alloy and the precise metallurgical processing it receives during manufacture. Whether the metal is annealed or aged is particularly influential on the subsequent machining properties. Alloys designed to reduce the use of rhenium, a rare metal that has increased tenfold in price in recent years as demand has increased, will be a likely next step. Advances in coatings utilising Plasma APS and EB-PVD are intended to provide improved wear resistance in the engine."

So what are the challenges when it comes to machining and working with advanced alloy materials, particularly when it comes to increasing cutting tool life?

ABOVE: François Arrien, AV&R Aerospace's vice-president for business development

ABOVE: Peter Smith, chairman and CEO Nasmyth Group

Smith continues: "All machine shops should have a real time coolant management system. Alkaline levels, PH testing, bacteria content and oil/water percentage mix are critical to the life of cutters whilst machining harder materials. Nasmyth Group has on-site testing to check all of the above criteria.

"The cutting tool industry has a huge part to play in the development of new coatings. Titanium Nitride coatings and in particular ceramic inserts are playing a vital role in prolonging tool life. Further developments are, however, still required to match the desire of design engineers to run and develop hotter engines and hence use more exotic materials. Other improvements that are becoming more prevalent are the use of specific CAD/CAM strategies designed for harder materials.

"Additionally Viper grinding in particular has led the way in multi-axis grinding with fir tree grinding and profile grinding becoming the norm."

Both Smith and Arrien believe that automation and robotics will have an increasing role in aero engine manufacturing as demand continues to rise.

"If we consider high volume blades or larger components a Flexible Manufacturing System (FMS) process is required," Smith says. "The robot can utilise a rail system to move in between the machines to deliver the parts if numerous machines are in operation, or a pallet transfer FMS can be introduced that negates the need for robotics.

"World class FMS systems can expect to achieve 98% uptime when truly optimised, compare this to traditional efficiencies where 75% would be considered amongst the best performers."

When it comes to the specific field of blade profiling Arrien explains:

"Besides the fact that robotic systems can work 24/7, precision levels required by new jet engine designs are not attainable manually. Using robots, AV&R Aerospace's automated blade edge profiling system creates high precision elliptical profiles on blades and variable vanes. To achieve these tight tolerances, AV&R's systems use adaptive and closed-loop capabilities coupled with final leading and trailing edge inspection. On turbine blades, these technologies can also blend the casting injection pins and polish the blades. This system is a perfect example of automation allowing jet engine manufacturers to achieve the precision levels required by new environmental initiatives and reducing labour costs."

Coping with composites

So how do developments such as composite/titanium fan blades impact on the manufacturing process?

"Automation suppliers will have to adjust their technologies to the new materials used in jet engines," Arrien continues. "Titanium leading edges for composite fan blades require long amounts of manual polishing operations. We have developed a titanium polishing robotic solution to do this operation automatically with much more repeatability."

Smith believes composites have their advantages but these may not apply to every component.

"A composite engine casing reduces weight by up to 1,500lb per aircraft, the equivalent of carrying seven more passengers at no cost. However, the impact on utilising composites in large volumes is not as 'easy' as first predicted. It is yet to be proven if high volumes on large products can meet the demand.

"Without doubt traditional blade manufactures will have to evolve and change with new manufacturing techniques and perhaps undertake a

RIGHT: MRO blade before and after AV&R Aerospace's robotic blending

ABOVE: AV&R's leading and trailing edge profiling system

relatively lengthy learning curve."

Aero engines, although reliable, demand expensive servicing and MRO costs that will need to be kept to a minimum in future for highly cost conscious airline operators.

Smith observes: "New and improved alloys, coatings, improved quality of product through improved machining and tooling strategies, moving away from welding and fabrication towards one piece manufacturing add to extending service intervals. With Finite Element Analysis software to underpin the designer's theories, engineers can predict with greater accuracy the failure rate or life of any given part."

AV&R Aerospace's technology specifically means that longer turbine and fan blade life can be achieved during engine overhauls.

"Our automated profiling system is a natural fit to address the high levels of variations found in MRO parts," Arrien explains. "Today, MRO compressor blades are mostly blended and re-profiled manually. By using an adaptive robotic system instead, the robot will greatly improve the aerodynamics of the blade. Better aerodynamics reduces turbulences around the blade increasing its life. Since the profiling system only removes the minimum amount of material required, it also reduces significantly the number of blades scrapped during manual repair."

I ask what impact the much lauded additive manufacturing (AM) process will have on engine production.

"Additive manufacturing has the advantage to create complex 3D shapes within very high precision, but unfortunately it generates poor surface finish," Arrien notes. "During manual polishing operations, the operator improves the surface finish but often compromises the shape of the part. By its consistency a robotic polishing system can polish without compromising the shape done by the additive process."

Smith concludes: "For the next five years, additive manufacturing has a small part to play in the rotative area of the engine. However, certification is problematic because of the issues surrounding the powder from which the parts are sintered; with the manufacturers struggling to produce identical-sized particles that are free from inclusions that in turn reduce the standard and accuracy of each individual part.

"The future for traditional subtractive manufacturing must be based on improved performance, faster removal rates - based on improved software technology, (CAD/CAM) improved feeds and speeds through motion enhancements, digital technology regarding feedback units, look ahead speed and processing speed of controllers.

"I predict casting will come under a greater pressure from AM compared to precision machining. Difficult and complex shapes lend themselves to casting and this is also an area where AM excels."

www.nasmythgroup.com
www.avr-aerospace.com

EXPORTWISE
Read it. Be it.
Brought to you by EDC

Automation Specialist AV&R Says Size Matters in Aerospace Sector

CHRIS FREIMOND

FEBRUARY 18, 2015

If there's one thing that Jean-Francois Dupont has learned about the global aerospace business over the past few years, it's that size matters.

Recognizing the challenges smaller companies face when striving to make an impact in a market where customers tend to be huge national or multi-national corporations, Dupont sought to bulk up the company he co-founded, Montreal-based aerospace automation specialist AV&R Vision & Robotics.

The result was a merger last year with automation manufacturer IMAC Automation to form AV&R, the world's largest aerospace industry robotics firm and one of Quebec's largest engineering firms specializing in automation.

With a staff of 120 people including 80 engineers, Dupont believes AV&R is now well positioned to grow its business globally.

"What we faced is a good lesson for any small Canadian aerospace company," says Dupont. "Consolidation is a must. There are many smaller companies offering similar services, but OEMs generally want to deal with just one supplier in a specific area and that's what we've created for our customers."

The merger created a company that can now offer more complete automation, robotics and machine (digital) vision solutions to its customers, he adds.

And with a customer list that includes Rolls Royce and Pratt & Whitney with manufacturing plants around the world, AV&R has to have the capacity to provide services where and when they are needed – and that's a challenge in itself.

"Once we've established a relationship with a customer, they expect us to be on the ground with partners and local representatives in their time zones and at their locations," says Dupont. "In some cases that means having people who understand the local business culture and speak the local language. These are challenges that any Canadian company looking to grow business overseas needs to consider."

He adds that even in the U.S. where customers could once be served by Canadian representatives who would periodically visit U.S. customers, American firms and U.S. authorities now increasingly insist that suppliers maintain a local presence including staff with U.S. citizenship.

Challenges like these don't deter Dupont. The U.S. remains AV&R's main target market and the company is planning to open an office there. His other two top markets are France where there's a growing demand for aerospace automation, and China, which is moving steadily towards more automation in manufacturing.

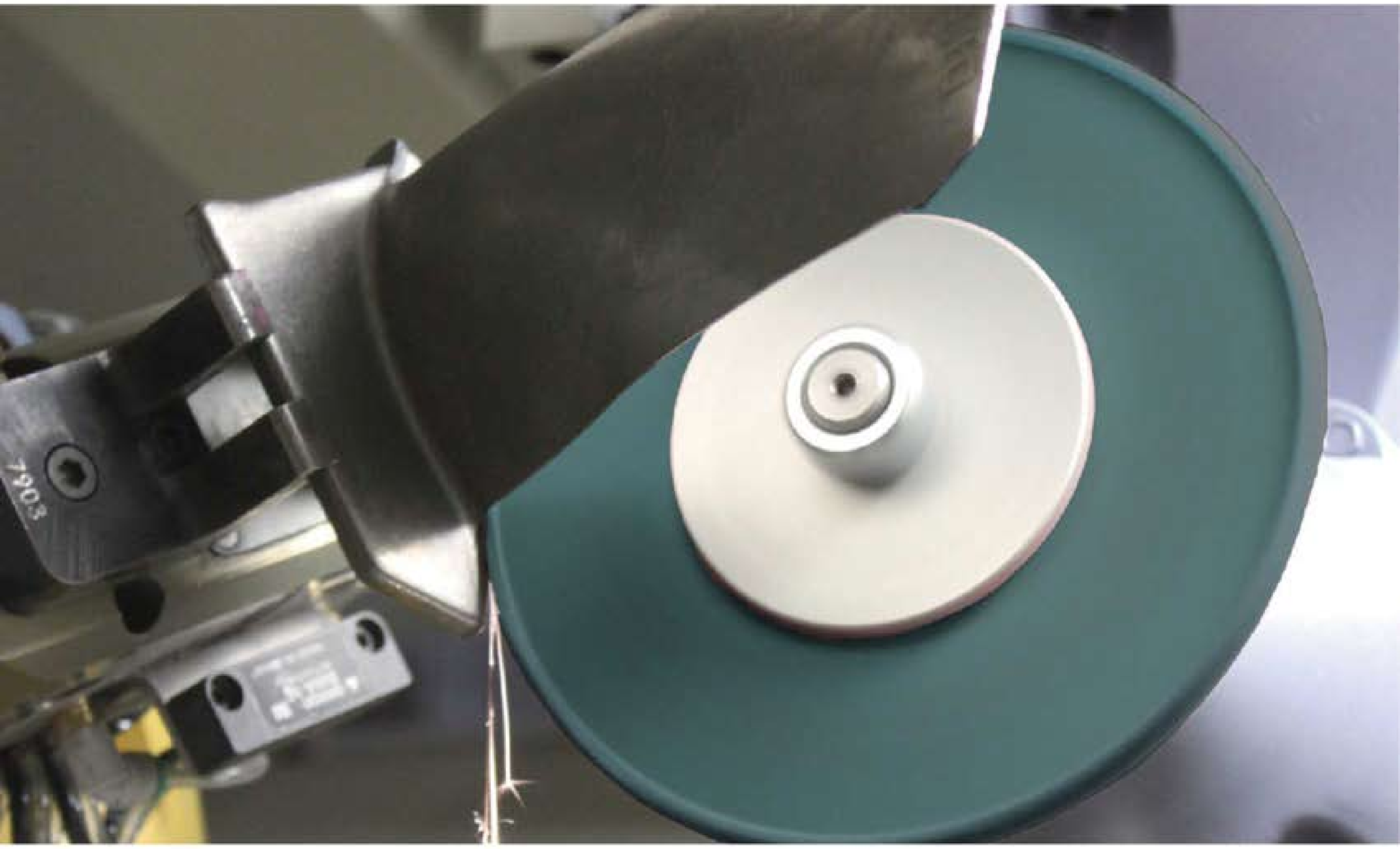
Export Development Canada (EDC) aerospace sector advisor, Robert Caouette, says AV&R's experience is typical of many Canadian companies looking for opportunities in the global aerospace industry.

"Canadian SMEs, although growing, are starting to lose ground in global supply chains compared to suppliers from other countries," he says.

"Most are simply too small to sell directly to very big OEMs like Airbus and Boeing, so their need to focus on building relationships with the tier one and tier two suppliers to the OEMs. That's where they can build business."

Tips from AV&R President and CEO Jean-Francois Dupont

1. **Consolidate.** Trump smaller competitors and appeal to global aerospace OEMs that prefer to deal with just one supplier in a specific area.
2. **Build focused core competencies.** Through its merger AV&R can now offer its customers complete automation, robotics and machine (digital) vision solutions, making it a specialized one-stop shop.
3. **Go to your customers.** Establish a local presence near to your customers, including hiring staff that understand the local business culture and language.



AV&R Vision & Robotics公司的机器人系统提供了飞机发动机的压缩机叶片的混合检测。

航天制造商的自动化流程
Aerospace Builders Automate Processes

随着拖欠的订单越来越多，航空航天/国防制造业对加工速度的要求越来越高。

航空航天业已经加快了自动化步伐。因为航天和国防工业都在试图加快自动化制造的进程，以满足不断增长的OEM订单和航空航天防御计划的时限要求。

随着航天/国防制造商不断寻求加快制造过程，许多公司正在从高度自动化的汽车行业中借鉴经验，包括移动装配生产线，并更多地利用自动化机器人。在商业航空中，老化的飞机被淘汰，转而采用更加节能的新机种，并且这种需求有着爆发式的增长，这也迫使飞机产能必须相应提升。

位于密歇根州Auburn Hills市的ABB Robotics公司北美区副总裁Joe Campbell说："航天和国防业的口头禅就是'我们产量小，我们不能自动化'。因为他们通常都是小批量加工，所以只采用手工制造，且对精度要求非常严苛。"

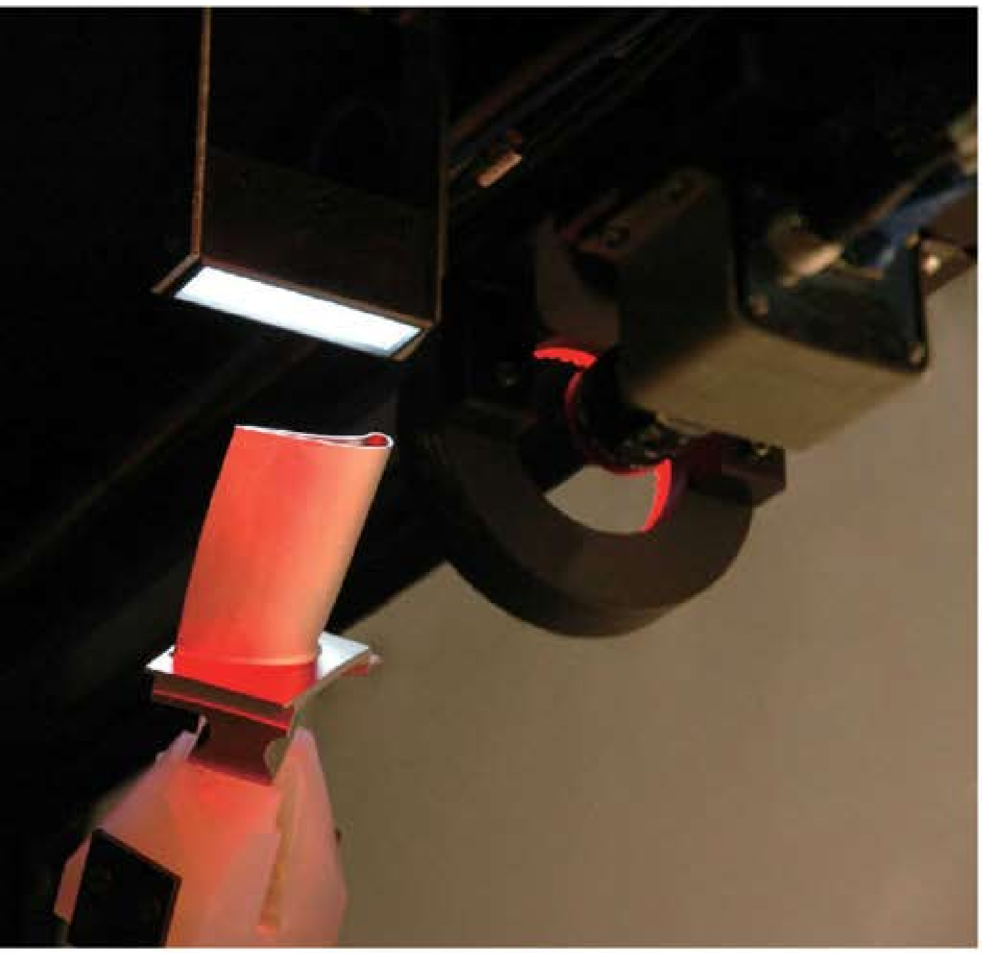
"从产品的角度来看，高精度、高准确度和高刚性的趋势相同。每一个产品都可以做的更好一点，"他补充道，"无论是在国防工业还是商用航空领域，我们现在需要发现和反映客户的要求，他们的需求量越来越大。他们从来没有像现在这样毫无产品积压——Boeing公司曾公开宣布他们已经将未来几年的飞机都卖

完了。那也就是说，如果你今天想买一架飞机，那你必须得等好几年才能拿到。"

随着乘坐飞机进行旅游和商务工作的人越来越多，航空公司在寻找一种新型飞机取代原来节能效率低的飞机，而今天越来越多的自动化使得飞机制造商更容易达成这一目标，Campbell提到。"突然间他们的产量增加不那么慢了。拥有足够产能的公司将会得到订单。"他说，"如果你能缩短加工时间，那么你将有可能赢得更多生意。"

备受瞩目的自动化

没有什么比为美军及其盟国制造下一代F-35 Lightning II喷气式战斗机这种高风险高预算的Joint Strike Fighter (JSF)项目更能体现自动化的重要性。在自动化的努力中，JSF已将其集成装配线（IAL）部署到了具体日期，该装配线由一家程序承包商——Northrop Grumman Corp公司安装，该公司位于加州帕姆代尔的羚羊谷制造中心，F-35的机身就在这里制造。



一台AV&R的视觉检测系统正在检测飞机涡轮发动机叶片表面。

在Northrop Grumman的IAL是一条生产F-35机身的高度自动化生产线，由德国Kuka Systems公司安装。基于在成本、规划、质量及客户满意度等方面的卓越表现，Kuka获得了Northrop公司2010-11年度顶级供应商大奖。Kuka Systems公司设计、制造和安装整个IAL需要超过1亿美金的预算，其包含了安装在78个刀位上的超过500种刀具，在Northrop Grumman位于帕姆代尔制造中心占地200,000平方英尺。该系统包含了自动化装配系统、运输系统和制造系统。

在Kuka获得供应商大奖的例子里，Northrop Grumman指出自动化集成了诸如设计、布局、制造、检验、项目管理和工具系统的接口等独一无二的特性。该航空/国防制造商还指出，Kuka Systems公司对于IAL的灵感也已被应用于全球的主要汽车制造商高度自动化和优化的装配生产线中。该IAL需要大量Kuka公司的工程师和其他技术人员在一起紧密合作，才能设计出一个高度自动化和完全集成化的飞机生产线。

Kuka Systems公司航空航天部副总裁Robert Reno说："Northrop Grumman是一个创新的探索者，其所支持的项目正在帮助验证自动化装配的概念是否可以在未来用于军用和民用飞机制造。"该IAL正在逐步投入使用。2014年F-35的生产数量达到峰值，IAL能够一天完成一个中央机身。

跟上自动化的脚步

随着这些年与一些企业合作，航空/国防工业的发展似乎已到达了临界质量。以Northrop Grumman为首的航天自动化协会（AAC）开始帮助制造商在航空/国防生产线中采用车载式自动化系统。（见"Modular Automation by the Aerospace Industry"，于2006年3月发表于Manufacturing Engineering）。同样一些自动化以及测量和软件开发商为了自动化在工业中的发展自发组成了Computational Manufacturing Alliance也可以称为Compufacturing（详见www.compufacturing.org）。其中，2011年三月在加州Anaheim举办的AeroDef 2011博览研讨会上，证明了多种技术的进步。

位于密歇根州Rochester Hills市的Fanuc Robotics美国公司，航空航天集成部的经理Chris Blanchette认为，集成自动化装配线在最近已经取得了一些成功，其主要成就包括

Fanuc integrator Comau Aerospace所安装的移动机器人。Comau的移动机器人系统安装在贝尔-波音的直升机工厂中。该公司还在Northrop Grumman为F-35的进气孔开发了自动化机器人钻孔工作单元。

“他们有一个安装在现场的移动机器人，工作状态良好。”Blanchette说，“并且现在他们开始连续获得订单。这也是对他们的一项挑战，对此很多OEM厂商都退缩了。该组织如此之大，所以他们的组织构架非常复杂，让他们认识到自动化功能并不容易。”

Blanchette还提到，在堪萨斯州的Wichita市有一些新的自动化供应商，他们组成了Great Plains Robotics Alliance（GPRA），他们也有着类似的AAC指令，试图将彼此通过航空航天业联系起来。“他们正在与机器人集成商和OEM商一起，评估机器人并进行系统测试。”Blanchette说，“对于OEM商来说，所面临的挑战是找出他们工作中将要使用的技术。他们并没有一个长期的收益计划，而且他们恐怕难以接受以下事实：航空航天的零部件非常昂贵，通常交货时间很长。”

他还补充说，大量积压的订单也使得航空航天/国防业的制造商面临更大的挑战，使得他们不得不探索更新的自动化技术。为了按时交货，制造商们不得不开发新的技术以满足生产需要。

机器人的发展动力

科技发展为机器人自动化提供了更好的精

Kuka Systems公司为Northrop Grumman公司的F-35所研发的集成装配线。2014年F-35的生产数量达到峰值，IAL能够一天完成一个中央机身。

度和刚度。机器人的主要应用还停留在商业和航空/国防工业的钻孔、铆接和紧固方面，Blanchette说，其中商业航空的公差可以到达0.01-0.03"（0.25-0.76毫米）而国防工业的公差可以达到0.005"（0.13毫米）。油漆和涂料的应用也在自动化应用中占有重要的位置，他说，在飞机发动机部件表面复杂并且对公差的要求高，这有着非常大的市场。他还注意到，检查叶片表面上的微观光洁度也非常具有挑战性。

位于加拿大Montreal市的AV&R Vision & Robotics公司是一个Fanuc Robotics集成商，其为飞机的关键旋转部件开发了自动化视觉检测系统，以及提供自动化机器人系统的精加工、分析、去毛刺、抛光和研磨。与该公司合作的主要飞机发动机制造商有GE、Pratt & Whitney和Rolls Royce。

"我们致力于机器人和视觉系统已有15年之久。"AV&R Vision & Robotics公司的董事长兼执行总裁，Eric Beauregard说。并且他还指出航空业占公司总业务的约95%。他说："我们现在开发了两个核心功能：自动视觉表面检测和对部件进行专业的精加工。大多数的飞机发动机部件，在某些地方都需要进行最后的精加工，而由于部件表面的多样性，这些精加工多事通过手动完成。"

自动化精加工

其中一个AV&R的客户采用其自动抛光系统，完成涡轮发动机外壳外侧边缘铝圈上的精加工。"我们已经为翼型件开发了一种自适应刨工工艺，其可消除无论是锻造工艺还是人为操作所带来的表面缺陷。"Beauregard说，"在发动机周围的叶片上，如果表面非常光滑，那么空气就可以很好的进入发动机，这也就是所谓的唇部表面。而在成型之后，这些都需要手工打磨。整个打磨过程非常困难，并且在打磨中所产生的铝尘对人体十分危险。"

在具有自适应的精加工系统中，飞机发动机制造商可以在整体工序中加入检测，他指出，这是飞机发动机应用的重要组成部分。"因为每一个工件都有不同之处，所以要每一个工件都适应加工工序，从而到达一个很高的精度水平。"Beauregard 提到，"如果想把一个工件加工到完美，那么不能干的如此盲目。因为每个工件都会有不同，而我们的自动化系统可以很好的适应它。"

他补充到，检查和修复涡轮叶片的价格昂贵并且废品率高，所以在其维护，普通修理和大修（MRO）方面也有着巨大的市场。在发动机的冷压缩机段中的翼型件是由钛合金制成，其质量很轻，并且在外部使用了陶瓷涂层，从而对其进行热保护并防止它融化。

"最关键最重要的是机翼前缘，热锻铸件的精度往往都不是很好，他们没有必要去对表面进行重新加工。但是当你观察那些冷锻的工件时，它们根本就没有任何精度可言。"他补充到，"我们所做的是测量每一个叶片的形状，允许误差为±0.002''。"Beauregard说"除了在大学实验室中，我们是唯一一家可以在工厂中进行最终质量检测的公司，因此我们创建了行业标准。"

他还提到，现在涡轮叶片的质检多是手工完成。"我们的目标是自动化视觉检测和精加工。"他说，"我们的最终目标是要对工件进行检查和修正。现在我们唯一缺少的是三维检测。我们将工件放置在摄像头下，通过操作软件即可发现表面的缺陷，例如坑、压痕和损伤。"

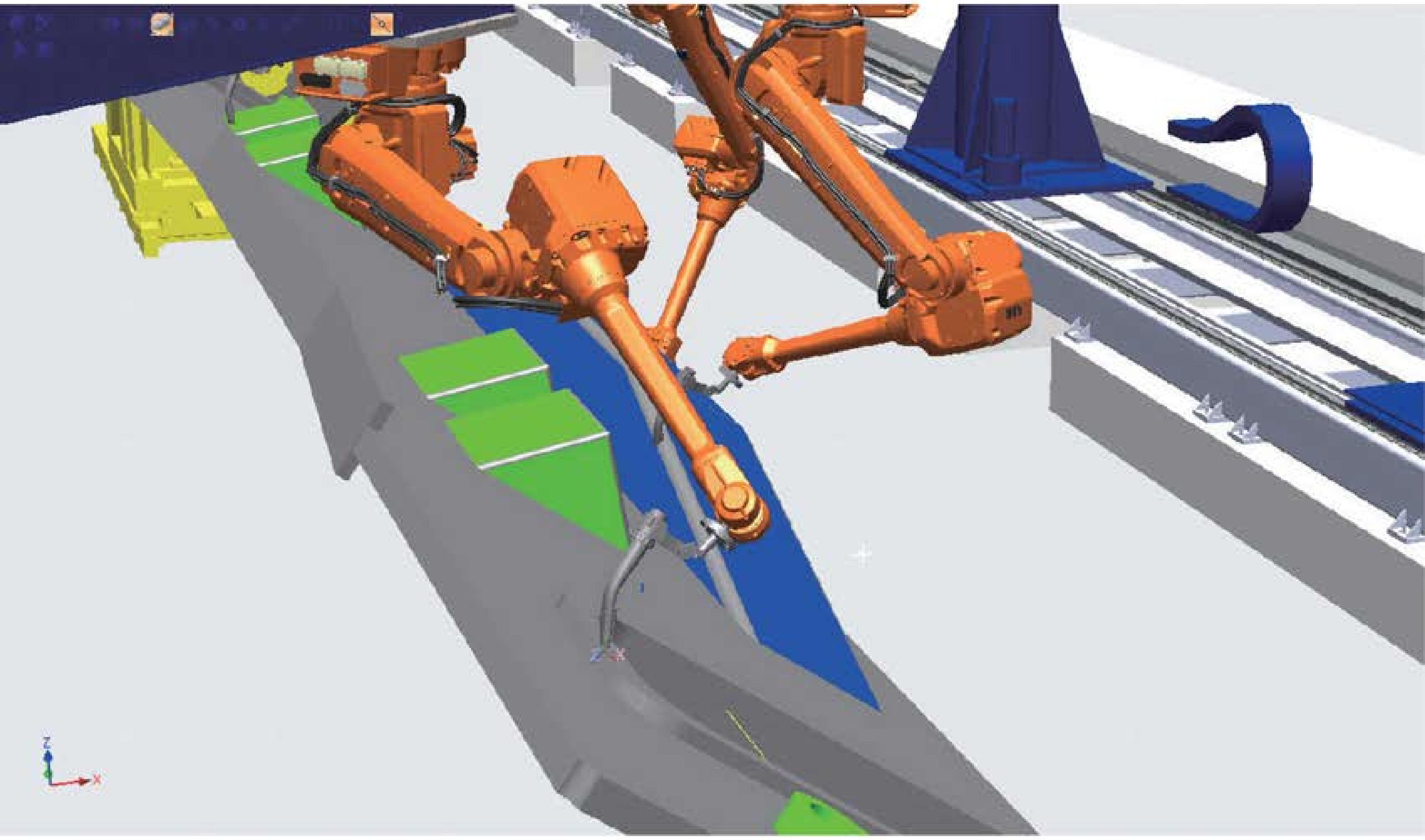
该公司去年与加拿大国家研究委员会签署了有关集成非接触3D测量系统的技术转让协议，所以公司也将在应用中提供更好的精度和测量速度。这项技术以前用于对NASA航天飞机吸热瓷砖的检测。Beauregard 说，"现在我们正在研究的是更高速和更高精度的3D数据采集，而这项技术在现在的工业环境中还没有。"

用于造船的自动化焊接

在造船应用中通常不考虑大批量的重型自动化，但是由于机器人焊接集成商，位于田纳西州Knoxville市的Navus Automation公司所提出的多通道高沉积工序，一台ABB集成机器人，在为美国海军下一代DDG-1000 Zumwalt级驱逐舰焊接大型钢板时，节约了大约60%的时间

"我们所制造的这个系统长度约为120'（36.6米），他包含了沿轨道运动的六台ABB机器人。"Navus Automation公司东北地区的副总裁Don Bernier指出。其公司的自动化机器人位于美国东北部的造船厂，被用于为在建的驱逐舰加快焊接速度并且提高焊接质量。他还说："我们一直在寻找一些可以改进焊接的制造工艺，其重量超过30吨。"

对于这种应用，Navus采用了在2个30米的轨道上安装了6台带有Fronius GP串联系统的ABB IRB 4600机器人，Bernier说。该系统可以在研磨的同时进行自我清洁，去除顶端附



ABB的离线编程软件RobotStudio模拟了Navus Automation公司在造船中的机器人焊接单元。

着的硅酸盐，以便满足光洁度的要求。"在焊接中，我们使层间温度保持在200-300℃。"他说，"工件需要预热。在工作单元共有六台机器人，每个单元有两个独享的焊接机器人，然后两个单元共享两个清洁机器人。"

"焊接的对象是一块2"（51毫米）厚的钢板，在焊接中必须被翻转四次。并且在每一步工序前都必须进行清洁工作。"他补充到，"我们已经取得了对焊缝进行UT（超声波检测）的资格，主要是检查哪些他们所谓的偏差或者焊缝本身的夹渣。它对不允许有太多夹渣，这是因为可容纳焊丝的熔渣和硅酸盐的地方非常小。这也就是我们要对其进行清洁的原因。"

数字化制造使得Navus可以为客用3D CAD建模软件设计工件程序。"他们通过一个嵌套的过程发送它，并将其保存为STEP文件，之后机器人工程师检索数据并做离线编程。"Bernier解释道，"需要花费大量的时间和经历去编程。"ABB的焊接经理，Mark Oxlade补充说，"对于这种工作，离线编程是必不可少的，而这些都可以通过RobotStudio来完成。"

由于此系统的帮助，制造商可以把最早生产周期为28周的工序缩短为8周。Bernier说，"他们可以同时制造3到4个工件，在造船时可以节约大约60%-70%的时间。"为此，该船厂正在打造有关的数据库，这也将有助于未来的舰船设计。

"目前正在使用的都是这些系统的初级功能。"Bernier指出，"有些舰船制造程序已经用了很长时间了，他们的设计不是在纸上就是使用2D模型。而随着3D技术的发展，这些会容易很多。"

www.abb.com/robotics
www.avr-vr.com
www.fanucrobotics.com
www.kuka-systems.com
www.navusauto.com