OPEN MIND Technologies *hyper*MILL
A Product Review

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Prepared by
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Foreword

CIMdata, Inc. prepared this product review as an independent and unbiased assessment of the functional capabilities of hyperMILL and related products, a CAD/CAM software product suite developed by OPEN MIND Technologies AG. This evaluation is one in a series of software product reviews produced by CIMdata, a worldwide consulting and marketing research firm. CIMdata has authorized OPEN MIND Technologies AG to reproduce and distribute this document, without constraints from CIMdata.

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1. OPEN MIND Technologies AG

OPEN MIND Technologies offers a comprehensive CAD/CAM solution, ranging from 2- up to 5-axis machining. The CAM company is a market and technology leader for 5-axis milling and drilling applications among worldwide CAM software vendors. They are viewed by CIMdata as an industry leader in providing software for positional and simultaneous 5-axis milling. The company has particular strengths in machining of multifaceted components for applications as varied as mechanical products, mold and die, automotive, aerospace, machine tool, medical instrument and jewelry design and manufacturing. With subsidiaries, offices and sales partners throughout Europe, Asia and North America, the company serves major markets worldwide.

OMT offers extensive resources to support 5-axis milling of intricate products, including impellers, blisks, turbine blades, tubes, pipes, tire molds, aerospace components, dies and deep cavities within molds. Capabilities encompass machine tool, controller, and targeted application solutions. The products support an extensive number of milling strategies and post-processors.

"Outside the Box" Thinking

OPEN MIND Technologies has developed a distinctive market and product strategy, positioning itself as "The CAM Force" to underscore its commitment to CAM software. OPEN MIND emphasizes its approach of combining innovative ideas with extensive experience and expertise. The *hyper*MILL suite represents flexible and versatile modules for automated programming, optimized processes and efficient manufacturing, developed by a knowledgeable and experienced team that continues to be an industry leader in terms of innovation and creativity.

Many innovative machining technologies and applications have been introduced by OMT. It was one of the first companies to extend 5-axis machining from aerospace applications to tool making and to offer 3+2 machining of deep cavities within molds. There are three CAD integrations for *hyper*MILL: *hyper*CAD/*hyper*CAD-S, SolidWorks® and Autodesk Inventor®. Modeling is mainly performed using *hyper*CAD, OMT's stand-alone modeling system.

OMT milestones include 3+2 machining, rapid result functionality, indexed milling and the use of adaptive-feature technology in 5-axis machining. OMT utilizes an advanced technology approach that turns 3-axis toolpaths into 5-axis without the need for exact guiding by points, vectors, curves or surfaces.

OMT Background

OPEN MIND Technologies was founded in 1994, and immediately established business relationships with Autodesk and Hewlett-Packard. Prior experience in the development of NC controls and 2-axis programming software facilitated the establishment of those relationships. OMT won Autodesk Developer of the Year in 1996, and in the following year established licensing relationships with Siemens and Hitachi-Zosen.

In 2002 OMT became a wholly owned subsidiary of the German firm Man and Machine, a software development firm and a distributor of CAD and PLM products with annual revenues of approximately $155 million. They are the largest Autodesk distributor worldwide. OMT operates as an independent entity within Man and Machine.

OMT has experienced steady growth since 2004 and now has staff of 210 with 11,000 end-user customers. Products from the *hyper*MILL CAM suite are currently used in more than 15,000 installations around the world. OMT holds patents in both Europe and the U.S.

Strategy for Growth

The OPEN MIND Technologies sales strategy is geography-dependent. Following on the establishment of its initial subsidiaries in Europe, the U.S., Singapore and Japan, the company has added subsidiaries in China, Taiwan and India. Most recently, it has established subsidiaries in Spain, Russia and Brazil. Additionally, OMT has a large network of sales partners throughout Europe, Asia, Mexico and South America.

OMT utilizes relationships with machine tool builders and' their dealers to identify areas for *hyper*MILL usage and represent their products. For example, seventy-five percent of the overall *hyper*CAD and *hyper*MILL revenue in Japan is through dealer networks of 5-axis machine tool builders in the Metal 5X-Partnership program. OMT Japan utilizes the marketing arms of partners such as Mazak, Matsuura, Makino, Mitsui, OKK, Okuma, Toyoda, Kitamura, Yasda, DMG and Hermle. In turn, OMT supports machine tool builders and their 'dealers on benchmark projects and sale of their machine tools.

Since OMT offers a complete 5-axis milling process, including consideration for the functions performed by the machine tool and controllers, they have established cooperative agreements with machine tool and controller manufacturers. These agreements define technical, sales and marketing responsibilities of each partner to cooperate in the development of 5-axis technology required by OMT customers.

The partners in this relationship are also utilized by OMT to support their sale efforts in Germany, France and Italy, although OMT also sells direct in these geographies. In other major countries, OMT has established subsidiaries in which a combination of direct salespeople and resellers are employed. They have approximately fifty resellers worldwide.

Present and Future Outlook

OPEN MIND Technologies is one of the most rapidly growing NC software vendors worldwide. In 2011, CIMdata ranked OMT as the seventh most rapidly growing CAM software vendor worldwide with a revenue growth rate of 14.7 percent over the prior year. This position is based on organic growth, unlike many competitors that have grown through merger and acquisition, or by combining CAM offering with their own enterprise CAD and PLM software. In 2012, OMT is ranked by CIMdata as the third most-rapidly growing vendor overall, with an annual revenue growth rate of 14.8 percent, and the most rapidly growing of vendors with revenue greater than $15 million. CIMdata has conservatively projected that in 2013 OMT will be the sixth most-rapidly growing vendor with a revenue growth of 12.4 percent over 2012.

*hyper*MILL Version 2013 was the version evaluated in this review. OMT completes a major release on an annual basis. Several smaller releases and service packs are provided several times a year.

2. *hyper*MILL

The geometry-oriented CAM solution *hyper*MILL provides a Windows-oriented, highly graphical user interface, 2-axis, 3-axis, high-speed cutting, mill-turn and industry-leading 5-axis milling capabilities for cavities, surfaces and specialized machining tasks. It incorporates leading-edge technologies and an integration capability for

CAD solutions, plug-ins, interfaces and post-processors.

Although OMT's industry leadership in 5-axis milling is one of its singular characteristics, CIMdata believes OMT is most distinguished by the value its solutions provide to the equity holders of its customers' businesses.

While many other products exist for producing multi-axis cutter paths, *hyper*MILL stands out for its usability by all NC programmers, regardless of their level of expertise. Its user-friendly capabilities facilitate error-free productivity.

Quality and Productivity

With a strong commitment throughout the company to flexible and integrated applications and ease of use, OMT gives its customers an edge in quality, productivity, profitability and return on invested capital.

Through OMT's combination of an intuitive, graphical and interactive user interface with carefully controlled programming options, it is able to deliver solid business results for its customers.

Figure 1: Full-Face Helmet Programmed by hyperMILL for DAISHIN SEIKI CORPORATION

With the *hyper*MILL capabilities, customers can quickly create one-off programs that have a level of sophistication and efficiency well above a particular user's level of experience, programs that can be safely allowed to run unattended on the shop floor at programmed feed rates.

To reinforce customer success, OPEN MIND Technologies emphasizes training and consulting services for customers' specific projects. In Germany, for example, OMT utilizes approximately 15 consultants to support client projects, working with each client to customize and satisfy individual needs.

*hyper*MILL Advantages

CIMdata considers the distinctive and advanced capabilities of *hyper*MILL to be:

- Its overall strength in both positional and continuous 5-axis milling.
- The flexibility provided by more than two dozen simultaneous 5-axis milling strategies.
- Specific application solutions developed and applied to machining of complex objects like turbine blades, impellers, tubes, pipes and tire molds.
- Its highly flexible and parametric programming approach for tire mold machining that aligns with the underlying design practices of tire product engineering.
- Its application of feature recognition and adaptive feature-based machining to 5-axis machining, as well as 2- and 3-axis operations.
- An industry-leading capability for collision detection and automatic avoidance applied to toolpath linking both within and between discreet toolpaths.
- Its development of robust comprehensive and machine-dependent post-processors.

- A user interface that lets users with limited experience produce advanced results, yet maximizes the potential production quality of highly experienced users.

Growth in 5-Axis Programming

5-axis machine manufacturing constitutes a growing stream of revenue for many machine tool builders.

The growth in 5-axis machines is the result of multiple factors:

- The tools are becoming less expensive.
- CAM-Programming is becoming less complex.
- The software functions are more powerful.
- Significant benefits can be obtained by machining some components with 5-axis tools rather than 3-axis machines.
- The capability for 5-axis milling offers the potential for greater manufacturing efficiency such as elimination of manual positioning, fewer setups and tool changes, the use shorter tools.

Additionally, 5-axis machines can be a cost-effective alternative to EDM and the electrodes they require. Reduction in the use of EDM for narrow and deep features in mold making also eliminates a great deal of complexity and labor in both the EDM process itself and in designing and programming the electrodes. EDM operation also requires significant additional CAD modeling to "protect" the surface where the "burn" is to occur. Along with the capital investment cost of EDM machines themselves, electrode machining generally requires additional special machines, equipment, holder inventory and carbon inventory, all of which necessitate another layer of management, maintenance and shop-floor space.

OMT is well-positioned to take advantage of this growing demand for 5-axis capabilities. CIMdata believes the company is enabling that growth. While this phenomenon is particularly true for mold making, OMT stands to benefit significantly from continued increase in the use of 5-axis techniques for processes previously limited to 2- or 3-axis machining—also a trend enabled by OMT.

''*hyper*CAD, *hyper*CAD-S, and *hyper*MILL

At the EuroMold trade show in Frankfurt in November, 2012, OMT offered a preview of its newly-developed *hyper*CAD-S software. *hyper*CAD-S, a flexible and versatile CAD system, is a high-performance solution for repairing surfaces and solids, performing quality assurance, and executing designs.

To further meet the modeling needs of their customers, OMT developed an interface that permits integration of *hyper*MILL software with the third-party design systems Autodesk Inventor and SolidWorks. Utilizing this internally developed interface, OMT is able to offer an integrated CAD/CAM solution to users of these design products so that they can continue to work with their familiar user interfaces. In this environment, *hyper*MILL runs directly within a CAD system.

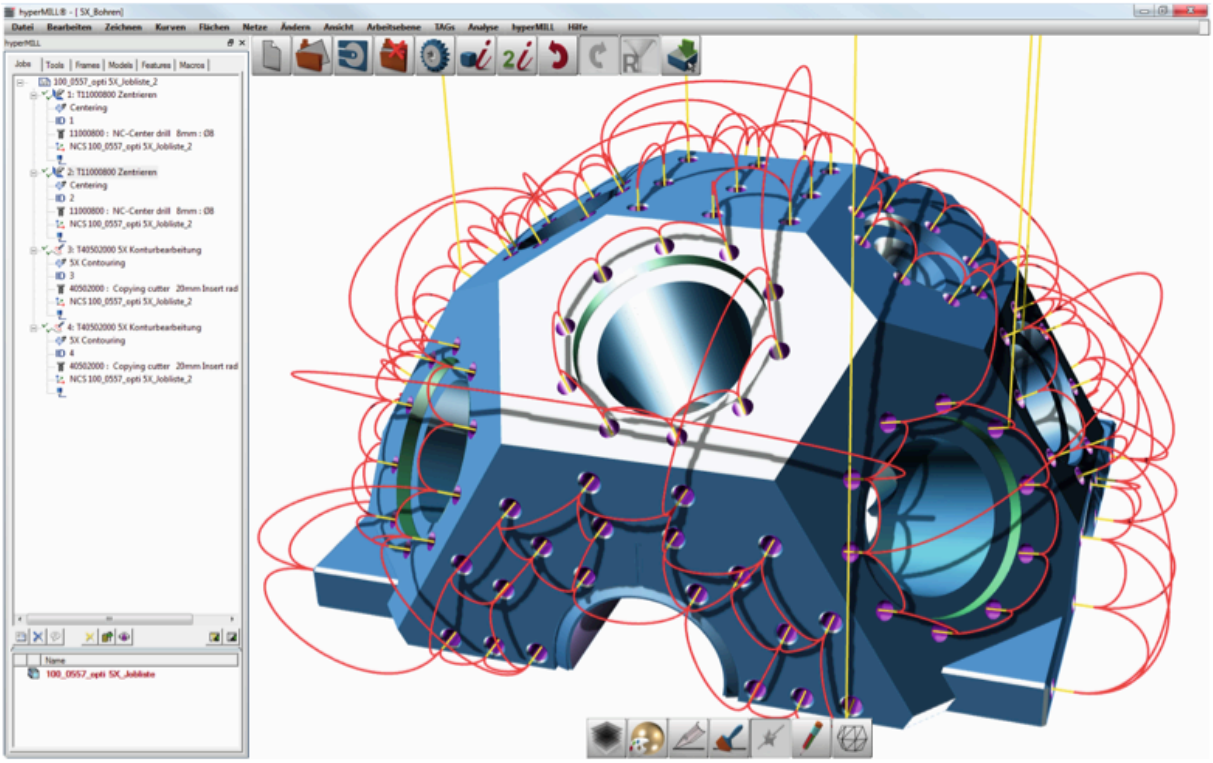

Figure 2: CAD for CAM

Operating Environment

*hyper*MILL employs a Windows-oriented user interface. It is intuitive, graphic and iconic. The same interface is used for 2-axis through 5-axis operations. The job list is well-defined and clearly structured, excellent graphics are shown for each parameter to illustrate the selected function and a short explanation is provided of the function and how it is used. The graphics and explanation can be very helpful to novice or casual users who may not be aware of the toolpath generated by a machining strategy or the impact of a specific parameter. With user-friendly features like these, OMT graphics support far exceeds that of most other products.

The underlying CAD platform *hyper*CAD was originally based on think3. The *hyper*MILL version 2013 introduces the new CAD- platform *hyper*CAD-S, completely developed and owned by OMT.

*hyper*MILL is also fully integrated within Autodesk Inventor and SolidWorks. To facilitate these integrations, OMT has created an interface layer or CAD shell between *hyper*MILL and the integrating CAD product. The *hyper*MILL side of the interface layer is always the same, but the design side changes to match up with each CAD product's interface to provide a complete integration.

*hyper*MILL is identical in each of the CAD environments. The user interface is that of the CAD product, so that within each environment the design-to-manufacturing interface has the same look and feel. *hyper*MILL functions are added to the standard design interface. *hyper*MILL directly accesses the database of the CAD system. Additional data is stored from *hyper*MILL, as the *hyper*MILL database is an add-on to the CAD database. The user works with geometry within the CAD product. When CAM functions are being performed, the user is operating in the *hyper*MILL native mode.

*hyper*MILL works totally inside the CAD system and it has direct access to all the design data. There is no data translation, as *hyper*MILL reads native CAD geometry. All CAD and CAM

functions remain on the screen at all times so the user can seamlessly move back and forth between CAD and CAM. Geometry associativity is also provided.

*hyper*MILL Job-Linking Strategies

Since most machining operations involve the eventual execution of a collection of individual tool-paths, it is ideal, within the collection, to link the end of one tool-path to the beginning of the next tool-path. In *hyper*MILL, job-linking allows multiple tool-paths with the same tool to be combined into a single operation. Connections between tool-paths are checked for collision, without continually moving the cutter to a safety position. *hyper*MILL automatically creates the ideal tool motions for those links to ensure that each linking move occurs at a safe distance from the dynamically updating stock model so as to avoid damage to the tool, the part and modeled fixtures.

In addition, *hyper*MILL is able to create continuous 5-axis linking moves from one tool-path to the next. CIMdata's observation of these and other capabilities being used in actual production machining is that they are impressive in terms of efficiency, safety, surface quality, and remarkably smooth machine operation. Job linking is available regardless of whether 2-, 3-, or 5-axis machining is involved.

System Architecture and Process Automation

Direct interfaces are provided between *hyper*CAD and most other CAD products. This includes direct interfaces with CATIA V4 and V5, Siemens NX, and PTC Creo, SolidWorks, and Parsolid. Direct interface with ACIS or ACIS-based systems are planned for the near future. Data translators are also provided in *hyper*CAD. The translators support IGES, STEP, DXF, DWG, VDA, Parasolid, and STL. The IGES translators are customized as appropriate to allow for idiosyncrasies in each of the differing CAD products. The user can also add templates to further customize an IGES translator.

Product Data Management (PDM), including file management for *hyper*MILL users, is accomplished in the native CAD environment. This includes support for all types of data such as parts, fixtures and molds. *hyper*MILL is written in C++.

*hyper*MILL, macros can define a sequence of machining steps comprising tools and technology data, and apply it to geometric features. The strong feature technology in *hyper*MILL further enhances the productivity possible through the use of macros. Macros can be assigned to a feature with a click of the mouse, to not only create cutter paths quickly, but to also maintain process consistency within the enterprise. The result is a collection of complete process-optimized toolpaths, produced while considering the model, materials, cutters and other parameters. Customized Process Features enable companies to define individual corporate standards for automated programming by linking characteristic geometry sequences with freely definable machining steps.

Manufacturers who develop proprietary manufacturing process automation applications can use the OPEN MIND API to automate recurring processes. As an example, a supplier of commercial aircraft wing skins optically scans wing profiles and through OPEN MIND's API, reshapes the data, runs an operations list, post-processes the information and delivers the NC program to the shop floor. The complete process is fully automated and requires zero user intervention during the entire process.

The OPEN MIND API architecture is modern Microsoft .NET technology, and supports established programming languages like Visual Basic, C# and C++. As such, integration can be achieved via XML web services, contributing to minimizing the effort to port the custom applications to new *hyper*MILL releases. It can be used within any PLM environment, and can use or provide information to/from other systems, such as a company's ERP system.

A number of development staff in OMT are dedicated to quality control, utilizing both interactive and automated testing. Algorithms are

tested automatically through test cases. The QC staff also manages the beta process, with an internal beta test followed by beta testing with specific customers.

OMT recently changed its methodology for managing their development process. The former approach utilized Microsoft Project for project management. Today, OMT uses Kanban principles to manage its development process. Kanban is one of a handful of agile methodologies. Its principles of just-in-time, limiting work in progress, and maintaining small batch sizes to reduce code in inventory, are designed to deliver higher quality results; on-time. CIMdata is favorably impressed with the decision to further improve the company's software development methodology, as it is yet another example of OMT's company-culture focus on delivering value to the customer.

Manufacturing Modeling

OMT released Version 1 of its newly-developed *hyper*CAD-S software, previewed in Frankfurt in 2012, and at METALL 2013 in Munich, Germany, in the Spring of 2013. *hyper*CAD-S is designed to be a high-performance CAM-capable hybrid surface and solid modeling software package for designing, editing, repairing, and analyzing surfaces and solids. It features an internally developed modeling kernel designed from the ground-up to support the additional demands that CAM places on CAD modeling. For example, the *hyper*CAD-S CAD kernel supports CAM objects ranging from toolpaths to display graphics. Because OMT controls the CAD kernel, they are free to add object support at any time.

*hyper*CAD-S, a 64-bit solution specially tailored to the needs of NC programmers, has been developed from scratch, with the architecture, core, graphics, database, user interface and API all being new software designs. Having full control over the *hyper*CAD-S architecture allows OMT to incorporate functionality that has especially high value in CAM usage, such as offering multiple area filtering that allow a variety of methods of selection; by color or layer, by geometric, system, or user defined properties. Workplane usage and manipulation is another CAD function heavily utilized in CAM. In *hyper*CAD-S, workplanes can be saved, including transformation and rotation data, and can be directly selected as references for moving and copying other data.

OMT's existing CAD modeler, *hyper*CAD, is a stand-alone OPEN MIND hybrid surface and solid modeling system based on the think3 kernel. Users are able to create, edit and modify complex surfaces, solids and wire frame models without limitations. With think3, automobile Class A surfaces can be produced. In this way it is similar to Dassault Systèmes CATIA and Siemens PLM Software NX. Surfaces can be manipulated and curvature continuity can be maintained. It includes a range of parametric features that are particularly helpful for generating objects and defining machining tasks.

A user can accept wireframe sketches, surface or solid models into *hyper*CAD, and NC programming can be performed on any type of model. The user has the option of converting wireframe or surface models to a solid or leaving them in their native state. The open solids feature allows a solid with a zero wall thickness to be generated from any model, combining the advantages of surface modeling with the easy handling of solids. A surface combined to an open solid entity and merged with a base solid to form a closed solid. A *hyper*CAD user can work in either a solid or surface mode, and solid and surface operations can be intermixed within the same model. The same modeling tools can be used independently of whether the model is defined in surfaces or solids, or a combination of both.

In *hyper*CAD, not only can geometry be accessed directly but the access also includes the feature tree, dimensional tolerances, GDT surface finish symbols, sketch entities, notes and other items related to the product definition.

OMT looks to the CAD partner to provide the necessary products for mold and die design. The model splitting and separation planes functions in *hyper*CAD or think3 simplifies the separation of molds into cores and cavities by using dedicated separation, extrusion and analysis functions. The global shape modeling function ensures that the

surfaces connect tangentially and continuously, a vital prerequisite for good milling results. It can also be applied to reverse engineering by employing deformation of original surfaces to fit to measured points or curves. Chemical and thermal shrinkage, spring-back and draft surfaces are calculated automatically. *hyper*CAD does not provide an automatic electrode extraction capability for mold design.

think3 provides a drafting capability. 2D drawings can be created automatically from 3D models, including multiple views, dimensions, and rich-text annotations. think3 maintains associativity between the model and the related drawing.

The capability to automatically compare design models to ascertain changes is a special tool in *hyper*MILL. It applies if model data are designed within the embedded operating CAD environment as well as when model data are imported via interfaces.

Basic Machining

*hyper*MILL provides an impressive hybrid machining capability. Depending upon the operation being performed, machining is done on either a tessellated surface or a combination of surfaces and tessellated surface. A tessellated surface is most commonly utilized by CAM software suppliers for machining, as it is typically faster and less likely to gouge. However, milling directly on a surface can result in greater accuracy. *hyper*MILL's combination approach permits direct surface machining to be cross-checked by also using the tessellated mesh. This automatic decision-making between the two techniques could be unique in the industry. Certainly the detail of the decision criteria and the methodology by which each mathematical model is applied is unique to the industry.

The job lists in *hyper*MILL are clearly laid out. All relevant data is automatically integrated and linked and can be recalled at any time. A model can contain several job lists, as would be the case for the core or cavity of a mold. Individual steps as well as complete job lists can be copied between different projects via a drag-and-drop operation.

In 2.5-axis milling, *hyper*MILL provides face milling, contour milling, pocket milling, playback milling, and rest machining. Face milling involves cutting flat areas in one-way or zigzag paths. Contour milling involves machining complex contours. A selection can be made between center path and contour path, including G41/G42 toolpath compensation. *hyper*MILL automatically prepares the contours, detects bottlenecks and self-cuts and prevents collisions with defined safe zones.

Within contour milling, multiple functions can be used for programming models with multiple contour areas or for machining automatically detected pocket features. Automatic identification of starting points can be used together with intelligent macros to ensure that in-feeds and transition movements are always performed in the most suitable areas for the technology in use. Additional functions are available to make effective use of selected tools.

Pocket machining encompasses path strategies that coincide with the possible form, condition and shape of the pocket, even if the pocket features islands and additional pockets, each with various heights and depths. There are distinct strategies for open or closed pockets (with or without islands), square pockets and circular pockets. The strategy always seeks to start where the plunging can occur outside the material. If that is not possible, a ramp or helical stepdown is made directly in the material, depending upon the type of tool being used. Pockets can be cut individually or, if thin walls are present, level by level. The bottom of pockets can be completely machined and canned cycles can be used for round or square pockets. Dwell time and rapid moves are always minimized and automatic feature recognition is possible.

Simple toolpaths can be generated manually with playback milling by moving the tool across the model with the mouse. Once the path is defined, *hyper*MILL can create a toolpath on the model following the defined path. If a potential collision is detected, it can modify the intended path so that

the toolpath always contains positions at collision-free points in the model.

Rest machining detects areas where the use of large tools allowed stock to remain, and calculates separate smaller tool toolpaths for removing that material.

Available drilling strategies include centering, simple drilling, deep drilling, drilling with chip break, reaming and boring, thread milling and drilling and deep-hole drilling. Drilling programming can be done in conjunction with the *hyper*MILL feature and macro technology. Helical drilling is supported, and within the limits of the tooling, the pitch of the spiral motion is user-definable.

Complex deep holes with various steps and cross-holes can be programmed separately. The in-feeds, drilling speeds, coolant and geometry elements like guide bushings, pilot holes and cross-holes can be controlled separately for different areas.

Significant efficiencies can be achieved when drilling multi-faceted parts by using *hyper*MILL's 5-axis drilling. The 5-axis drilling function can automatically program drilling operations using a variety of tool inclinations within a single operation. An automated function calculates the tool inclination and connects all drilling reference points for the best possible path. The user can define a preference for either A-axis or C-axis rotation, if such a motion is required.

It is possible for certain drill patterns to define a clearance plane very close to the part, eliminating the need for the tool to repeatedly go to a safety position. For the machining of different drill patterns with different tool inclinations, additional retraction positions can be defined that reduce the path length. Movements between drill holes and between individual machining planes are automatically checked for collision against the model. If collisions are detected, the cycle automatically positions the tool on a collision-free plane.

A range of roughing strategies is available in *hyper*MILL. In Z-level roughing, complete machining can be performed by machining with a constant stepdown and then re-machining automatically. Under some circumstances, an intermediate step with a small stepdown is automatically inserted. Z-level roughing can occur from the inside out or outside in. Offset roughing is available for blanks defined by the final part shape plus a stock allowance, as with a casting. A trochoidal cut can be employed in combination with other strategies when deep material is encountered in roughing. It employs a circular cutting motion that is partly in and partly out of the material.

*hyper*MILL includes rapid result functionality, a distinctive and relatively uncommon capability for automatic mistake avoidance. The software provides built-in intelligence to alert a user to potential problems. It performs plausibility checks, with data entry errors detected, marked and described in error and warning messages. It can detect erroneous feed parameters, incorrectly dimensioned tools and inappropriate machining strategies. Characteristics of the machine tool are considered—alerting the user to such issues as a clearance plane set too low, a toolpath programmed to go outside the range of the machine or an inefficient path is taken from one strategy to another.

OMT takes a totally adaptive approach to knowledge-based machining, as compared to implementing a rules-based methodology. *hyper*MILL employs adaptive machining concepts within a job stream by storing parameters that have already been run so that they can be re-generated to re-machine either an entire job or an individual feature. The user can create or capture process templates and re-use them in similar situations. The template can be stored in an information system for efficient retrieval.

Advanced feature technology has been implemented in *hyper*MILL. Commonly used in the industry to support 2-axis operations, features are often available for mold making, contours, pockets and planes. Within *hyper*MILL, features and macros are employed to automate all processes, from 2-axis hole making to 5-axis operations. Features can be defined for 3D contours, 3D strategy curves, surfaces and surface

groups and structured models for complex objects like impellers or mold core and cavities.

To provide added programming flexibility, *hyper*MILL features only include the geometry, not the machining strategy. Aspects of the geometry like height, length and corner radius are captured within a feature. Macros are used to define a machining strategy. Macros include operation, strategy, tool selection and appropriate parameters. Stored in a database, features and related macros are independent, so that any feature that defines the geometry can be associated with any macro that defines the machining strategy.

Frequently-machined parts can be turned into features. Either a feature or a macro can be re-used many times as is, or the feature or macro can be modified as required. A feature browser is available to retrieve a feature or macro and place it into the job list. Information such as description, time created, user, and material can be used to help identify a specific feature or macro. Several features can be combined and assigned to a machining strategy. By use of adaptive features, existing production know-how is readily available.

OMT has internally developed feature-recognition software in *hyper*MILL as an extension of feature-based machining. Using the software, *hyper*MILL is able to analyze a model and either automatically or interactively recognize features such as faces, closed and open pockets, holes and counter-bored holes. The same features can be put together in groups and arranged in feature lists. Components may be searched within a specified range for holes, either with the same orientation and depth or with a different orientation for multi-axis machining. Rather than program each hole separately, a definition can be copied from one hole to machine all other holes in a given range.

The feature-based machining implementation by OMT encompasses a number of advanced capabilities and strengths, including:

- Re-use features by applying a template.
- Flexibility provided by features and macros independence.
- A browser to search the database of features and macros.
- Internal development of feature-recognition software to support feature-based machining.
- The application of feature technology to all milling, including complex 5-axis milling and drilling.
- OMT post-processor support.

OPEN MIND Technologies promotes the use of *hyper*MILL both in an off-line CAM room and on the shop floor. In each case the product is identical. OMT does not modify the application to fit either usage or have a specific product for the shop floor. CIMdata does not view this absence as a disadvantage, believing rather that *hyper*MILL's highly graphical and intuitive user interface, its practice of carefully coordinating machining options with a particular machining strategy, and automatic collision avoidance technology are coordinated in a way that provides both safety on the shop floor and full-featured productivity in the CAM room.

3-Axis Milling

*hyper*MILL offers roughing based upon current stock calculations. Remaining stock is automatically identified by comparing the in-process stock to the finished model. The stock calculations can be generated from a solid model, a surface model, revolved profiles, extrusions, or from any prior machining process. Options enable the use of roughing strategies for semi-finishing and rest machining. Resulting tool-paths can be automatically optimized through a variety of optimization functions, including automatic in-feed calculation.

*hyper*MILL provides an industry-competitive 3-axis milling capability with a wide variety of finishing strategies. They include:

- •Six profile finishing strategies with three optimization functions including optimized scallop height machining.
- Four Z-level finishing strategies with four optimization functions including undercut machining with lollipop shaped cutters.
- Six automatic rest machining finishing strategies including undercut machining with lollipop

shaped cutters, each with four optimization functions.

- Finishing for prismatic parts including electrodes, small inserts, and complex 3D die tooling—a combination of Z-level finishing and profile finishing.
- Equidistant finishing for models with both flat and steep areas.
- ISO-machining for precise 3D equidistant machining of either individual surfaces or a selected set of surfaces, including a 3D spiral in-feed option. Tapered tools are supported.
- Freepath machining for simple engraving and edge milling.
- 3D rework machining to create cutter paths from previous jobs where a machining strategy's properties have changed.

For control of toolpath stepover, *hyper*MILL offers a variety of options. In roughing it offers a constant stepover distance that is measured above the surface of a part using a formula, such as establishing the stepover distance as a percent of the tool radius. In finishing operations, stepover options include control of stepover distance by scallop height, a 3D equidistant or one-part stepover that measures the stepover distance along the surface of a part, and an angle stepover for radial machining.

*hyper*MILL makes extensive use of rest milling in 3-axis operations. The amount and location of rest material is computed by having knowledge of the original stock, final part model, toolpaths previously generated and cutting tools that have been employed. This permits automatic attention to material left behind as a result of tools being too large to reach fully into corners, valleys or depressions. In rest machining, a smaller cutter or a cutter with a smaller corner radius is selected and a toolpath that machines only in those areas in which material remains is created.

High-Speed Machining

*hyper*MILL employs high-speed machining in either roughing or finishing operations. *hyper*MILL features that support high-speed milling include:

- Path changes and corners are automatically rounded.
- Soft helical or ramp-shaped movements are standard in start-up or plunge strategies.
- Smooth linking is established between paths.
- Equidistant cycles are used to guarantee true scallop material removal.
- A spiral-shaped in-feed for open profiles.
- Trochoidal movements to support longer tool life.
- Rest milling utilizes slope-dependent milling.
- Z-constant milling for steep areas.

Collision checking and avoidance is an important function, especially when machining deep cavities, domes with steep walls and undercuts, or when machining in difficult-to-reach areas with complex cutting tools. CIMdata believes that *hyper*MILL employs excellent collision checking and avoidance capabilities. The software takes into account the tool, shaft, holder, and back of the tool in its computations. It also recognizes more complex tools and holders, such as a lollipop cutter and those with a thick shank during collision checking and avoidance.

If a collision is detected, *hyper*MILL offers the user several options. The user can stop the cutting before the point of collision, change the tool length, clip away everything that would collide with the tool assembly, or revert from 3-axis to 5-axis and change the tool orientation. In the clipping operation the software automatically pulls out a segment of the toolpath and then re-combines the remaining portion into a new toolpath. If appropriate, the software will automatically move into 5-axis mode to tilt the tool. Once the tool is past the obstacle the software will return the tool to its original mode and original path.

The software bases the collision detection and avoidance calculations on the use of an in-process model, as compared to the final part model. By knowing the actual state of the stock, tool breakages and damage to a part or tool because of collisions are minimized. The in-process model is continually updated as material is removed. *hyper*MILL constantly tracks the exact dimensions of the component being machined. This is a more accurate technology to employ to

better represent the dimensional state of the part during a milling operation.

5-Axis Milling

OPEN MIND Technologies is thought to be the first CAM vendor to apply 5-axis positioning, or 3+2 machining, to the cutting of high, steep walls that are often found in molds and dies. In this operation, the tool can be tilted relative to a machining plane. This type of machining permits the use of shorter tools for deep cavities and in doing so creates more conditions where collisions are avoided.

The process of 3+2 machining is particularly important for cutting multi-sided parts on 4- and 5-axis machining centers. *hyper*MILL automatically calculates all necessary shifts and tilts for 3-axis machining with the shortest possible tool. As short tools are generally more rigid than longer tools of the same diameter and configuration, machining efficiency is greatly improved. It enables flexible setup, reduces the number of setups that might be required, and reduces the need for special clamping jigs. 3+2 machining is common now and is a familiar practice.

Automatic indexing is a distinctive patented 5-axis strategy that appears to have been first developed by OMT. It provides automatic calculation of milling areas with collision-free tool inclinations. If possible, the software finds an angle in which the entire toolpath can be machined without a collision. If not, the tool axis is moved only if and when necessary. It then lifts the tool from the surface, changes the tool angle, moves the tool down to the surface and machines until a collision would occur, at which point it will change the tool angle again and machine again.

Auto indexing results in time savings and permits the use of shorter tools and more rigid tools. In auto indexing, tool wear develops from top to bottom of a part and not by segment. This results in an improved appearance, since the change is continuous and hand polishing may not be required. Because 5-axis simultaneous movement does not occur at the surface, less dynamic behavior of the machine tool is required. Therefore, this strategy also works well with older or larger machine tools.

Continuous 5-axis machining is a strategy that offers a number of advantages over 3-axis, 3+2 machining and other machining processes. These include a reduction in the number of individual operations required, use of the most rigid cutters, greater accessibility and the ability to machine undercuts. This option often can eliminate an EDM process.

Further, simultaneous 5-axis machining permits the tool axis to be kept at a constant angle to the work surface, resulting in improved surface finish. For complex shapes, users can machine 5 sides of a part without special fixtures, jigs or manually re-positioning. The ability to reorient a tool in mid-cycle to allow milling, drilling and tapping with only one setup also can be a significant benefit.

Different to all traditional methods which mainly depend on surface normal or curve direction, OMT supplies strategies which create optimized, smooth, and collision free toolpaths automatically, independent of surface properties and local surface quality. All tool inclinations are automatically generated with collision avoidance of tool shank, holder and spindle nose taking into account arbitrarily complex shapes including fixtures and machine components.

While 3+2 machining has many benefits over 3-axis machining alone, the reality of most high and steep walls geometries are such that, to achieve optimum efficiency, they are likely to require several different positioning tool inclinations. By applying *hyper*MILL's 5-axis simultaneous machining, tool inclinations are continuously applied to precisely match the condition of each milling area. Due to the use of *hyper*MILL's automatic collision checking and avoidance, programming is easier, surface results are better and cutting time is further reduced.

There is no difference in the user interface between the 3-axis module and the 5-axis module. Because the software is easy to use, specialists may not be required to produce complex

machining results. The overall strengths of OMT in continuous 5-axis machining include:

- The focus on 5-axis technology that permeates the company.
- The process orientation and complete solution provided, including consideration for the machine tool, controller and NC software.
- The extension of adaptive feature-based machining to include 5-axis machining strategies or cycles.
- The individual application solutions available for machining of specific complex objects, like turbine blades, impellers, pipes, tubes and tire molds.
- The high, comprehensive quality of post-processors offered.
- The Metal 5X-Partnerships that OMT has forged with 5-axis machine tool builders and controller manufacturers.
- The high quality of the OMT and reseller customer support staff for 5-axis operations a— the focus of the company.

Generic machining strategies available to *hyper*MILL users for 5-axis simultaneous surface machining include:

- Contour with any number of predetermined curves.
- 5-axis drilling to create holes in the direction of the surface normal.
- •ISO top milling in which the milling toolpaths are oriented to the U and V lines.
- Extended top milling for multi-surface milling in which the milling paths are defined parallel to the axis and parallel or horizontal to the guide curve.
- Swarf cutting with the side of the end mill, as compared to the use of a ball or bull mill.

While commonly used 5-axis strategies like through-a-point, curve, and line are also supported by OMT, they are not recommended since these strategies can lead to unnecessarily large movements of a critical axis. Therefore, *hyper*MILL often uses a solution toward-a-point, curve, or line. In this way, OMT can keep the axis fixed as long as no collision occurs. *hyper*MILL is able to perform simultaneous 5-axis multi-surface machining without restrictions, such as those relating to the quality of surfaces.

Although dies, cores and deep cavities can be machined by 3+2 techniques, they can often be more effectively machined using 5-axis simultaneous milling, since 5-axis milling results in continuous material removal. The machining strategies available in *hyper*MILL specifically for 5-axis cavity finish machining include:

- Z-level finishing with simultaneous machining, for machining steep surfaces as a series of progressively deeper pockets.
- Profile finishing with automatic indexing; for flat or nearly flat surfaces.
- 5-axis equidistant finishing with simultaneous machining, for especially smooth transitions between individual toolpaths, in a single operation.
- 5-axis freepath milling with automatic indexing to mill engravings without collisions using short tools, even near steep walls.
- 5-axis rest machining with simultaneous milling or automatic indexing, offering all the options of 3-axis rest machining in addition to 5-axis tool positioning; automatic indexing determines the positions and areas that allow the part to be completely machined in a single operation.
- 5-axis rework machining with simultaneous machining, useful in converting 3-axis programs into 5-axis programs.

For machining of large, moderately arched surfaces, 5-axis top milling automatically adapts tool tilt angles to ensure high surface quality on concave surfaces. With this strategy, greater step-over between adjacent paths can be used, reducing cutting time. The strategies capabilities include:

- Since it uses in-feeds and stock detection, this strategy can also be used for efficient 5-axis roughing.
- 5-axis contouring for milling grooves, scribing, engraving, deburring and chamfering uses the side of a curve with a fixed orientation to the surface to guide the tool. This strategy allows the user to manually change the tool orientation for an entire area or for a specific area, if necessary
- Swarf cutting machines the workpiece surface with the tool flank. Large step-overs between paths or full-depth cutting reduces milling time and improves the workpiece surface. Swarf cutting is also suitable for roughing or combined semi-finish and finish operations. Advanced swarf milling techniques machine both side

walls and corner radii, reducing the need for rest machining.

- A new 5-axis shape offset roughing and finishing strategy offers a simplified and time-saving approach to programming shaped and wrapped surfaces.

A new feature of *hyper*MILL is shape offset roughing and finishing—for simple, time-saving programming of shaped and wrapped surfaces. Overall, OMT reports, the 5-axis technology in *hyper*MILL can typically yield time savings of more than 25 per cent while lowering tool wear and increasing contour accuracy for more cost-efficient production. CIMdata considers OPEN MIND Technologies to be an industry leader in 5-axis simultaneous milling.

Nearly all CAM-specific software is developed internally by OPEN MIND. The company maintains a licensing agreement with Celeritive Technologies, using their Volumill toolpath kernel as part of OMT's *hyper*MAXX high performance roughing strategy. Recent application of this technology to multi-axis through the shape-offset roughing machining strategy is an example of its use in multi-axis machining.

CIMdata is favorably impressed that OMT has extended adaptive feature-based machining from 2-axis to use in complex 5-axis applications. With adaptive feature technology, complete machining sequences that have already been run successfully for similar jobs with the same material can be imported via drag-and-drop. Feature technology can be used to copy a complete machining process from a similar part.

In addition to basic simultaneous 5-axis milling, cavity machining and feature based machining, OMT provides additional solutions for a number of specific complex applications that require or more effectively utilize continuous 5-axis milling. The number and leading-edge functionality of the distinctive solutions offered by OMT provides an advanced and rare capability. The application solutions include those for 5-axis simultaneous milling of impellers, turbine blades, tire molds, pipes and tubes.

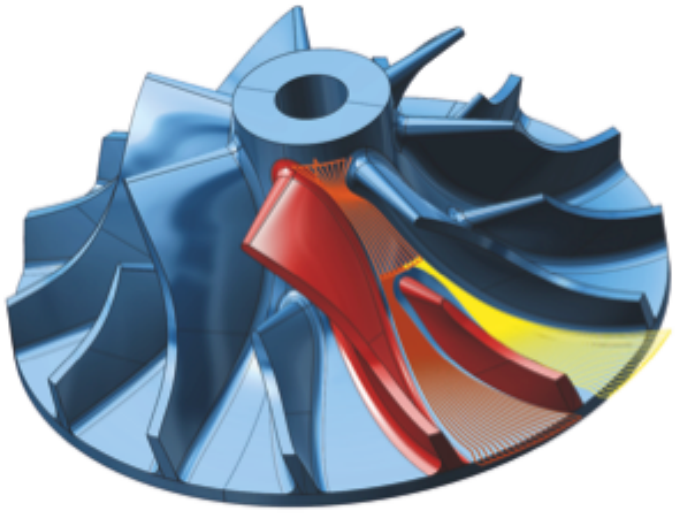

Figure 3: Multiblade Machining

Multiblade Machining

A wide range of simultaneous 5-axis milling strategies are specifically available to optimize the process for multi-blade machining of impellers and circumferential machining of blisks. The special cycles available for multi-blade machining include:

- Roughing in a continual process.
- Plunge roughing.
- Hub finishing of the base surface including rest machining.
- Point finishing that is appropriate for high-speed cutting of curved blades.
- Flank finishing for swarf cut machining.
- Leading and trailing edge milling.
- Fillet milling for when the radii between the hub and blade surfaces vary.

In addition, feature-based machining can be applied to impellers by defining the shape of the blades and an impeller and by generating a macro to establish the machining process for each blade. By doing so, *hyper*MILL is able to capture the geometry and machining process so that the information can be re-used without having to recreate the cutting operations for each blade, or

selecting blade geometry repeatedly for different job steps.

Single Blade Machining

Several specific strategies are available in *hyper*MILL to support continuous 5-axis machining of single-blade turbine blades. Because these strategies are specifically used for single-blade turbine blades, programming time is extremely short. A technique of "3D arbitrary stock roughing" is used to machine freely definable stock from various directions. "Top milling" is used for the finishing of the blade's aerodynamic surface. In the transition area between the blade and its root, swarf cutting can be used to machine the surfaces that cannot be milled using top milling, and "blade fillet machining" optimizes finishing at the transition between the blade and the root's swarf machining. A series of 2- and 3-axis strategies are specifically available for machining the blade platform and root sections.

Tire Package

OMT supports the 5-axis machining of tire molds, which are particularly complex objects to machine. Tire molds are designed with various 3D elements (pitches) of different sizes that are assembled using defined patterns. *hyper*MILL adopts the same logic used in the tire design, and applies this with automation to simplify the programming and machining of these complex objects. *hyper*MILL allows the user to program each pitch once, and then applies a set of utilities to replicate patterns and trim the toolpaths to the machining stock to assemble the radial segments of a tire mold.

The unique 5-axis shape offset cycles for roughing and finishing dramatically simplify the programming and allow the user to generate optimized toolpaths on a revolved shape as they might in a simple 3D mold environment. This process can also use *hyper*MAXX high-performance roughing in multi-axis. Also employing a distinctive retract process, *hyper*MILL fully checks the retract distance required to machine and safely crosses over each rib in a mold segment.

OMT's first project for its tire application was with the Italian company Marangoni in 1999. Since that time OMT has acquired significant business internationally, gaining a reputation as a world-class solution for model-less tire mold tooling production. OMT has continuously improved its solution since its introduction. While the preponderance of building tire mold tooling today still uses non-direct machining methods, there are both technical and financial advantages to manufacturing tire mold tooling through the use of direct machining.

As such, in 2010 OMT made the decision to invest further in their solution. In addition to applying the general 5-axis functions of shape offset machining, ISO machining, rest machining and mill-turn, OMT introduced utility functions for tires such as side shell wrapping and radial wrapping of CAD geometry and toolpaths.

In *hyper*MILL 2013, OMT has introduced an entirely new generation of the tire package using .NET-based definitions of characteristic features and toolpath planning within a dynamic browser-style wizard. In a single environment, users can undertake CAD preparation, programming, simulation, post-processing and tool management. Just as in the *hyper*MILL product in general, many tool styles are supported, including bull-nose and square-end cutters, conical tools and barrel cutters.

Half-Pipe Machining

OMT provides a specific milling strategy for 5-axis half-pipe machining. It is appropriate for milling pipe bending dies, hydro-forming dies, the core to draw endless plastic pipes and other parts with undercuts that can't be milled by simple 5-axis contour milling. 3-axis operations with multiple fixed-tool inclinations are difficult to program and might not meet surface requirements. With *hyper*MILL's strategy, these geometries can be machined in one step.

Mill-Turn Machining

OMT's millTURN module is completely integrated with *hyper*MILL and allows users to combine milling and turning strategies in a single program. *hyper*MILL millTURN integrates turning strategies for roughing, finishing, grooving, thread cutting and drilling. Lengthwise, planar or contour-parallel roughing is possible. During finishing, various approach and retract macros enable optimized machining. Falling contours can also be taken into account. The tool database supports cranked recessing tools as these tools can be used in the turning inclined grooving strategy. Through the use of mirrored feedback, the user can verify process reliability through visualization.

Utilities like stock models, tool database, and post-processors can be shared between milling and turning technologies.

Toolpath Simulation and Machine Tool Control

The graphics and visualization provided in machine simulation are excellent. The complete machine tool can be seen as well as the part-and-cutting tool. These models are clearly displayed and provide graphical simulation of the machine movements and toolpath. The software includes several important functions:

- By turning on the visibility of the milling paths for one or more job steps, the user can prevent overlaps from occurring; individual paths are better displayed.
- Flexibility in color selection allows display of individual job steps.
- The machine simulation includes all machine movement, plus collision avoidance.

OMT takes pride in its post-processor development. The post-processor translates the neutral description of the toolpaths, movements and commands to a specific controller and machine tool combination. Its engineers believe that this technology gives their customers a key competitive advantage. It offers a capability for adapting to the machines' specific functions and for optimally using the intelligence of each type of controller to meet customer requirements.

OMT provides solutions to control varied machine types, such as indexed or 5-axis simultaneous machining. OMT focuses on bringing together the machine tool, controller and the post-processor into one operating solution.

They support machine tool features and functions by providing direct-export of machining process data to both Vericut and NC Simul, both widely used external machine simulation software products. All the necessary *hyper*MILL data is transferred transparently, and automatically positioned on the machine.

3. Summary

The extensive capabilities of Open Mind Technologies' *hyper*MILL means that users limited by the 2-axis and 3-axis capabilities of their existing equipment are supported because OMT's products minimize risks in expanding to 5-axis equipment. Along with providing superb 5-axis functions, *hyper*MILL can improve efficiency for 2- and 3-axis work already on order while enabling development of new business lines.

With flexible, integrated applications accessible to users both highly skilled and limited in experience, *hyper*MILL offers improved efficiency, productivity and enhanced profitability and return on investment. *hyper*MILL's broad range of capabilities make OMT a preferred solution provider for industries as diverse as machine tools, automotive, aerospace and medical instrument design and manufacturing.