NPDT
The Future of Design is Now

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ABSTRACT

The Next Generation Project Development Team (NPDT) at the Jet Propulsion Laboratory provides a customer with a state-of-the-art Concurrent Design and Analysis environment for the early Design stages that emphasizes a total Systems approach, and features Multi-Disciplinary design teams, and interconnected, high-end Analysis and Design tools. These tools share and utilize a common 3D geometry of payload and spacecraft for their analyses and design. The NPDT provides support for payloads, probes, rovers, and dedicated SC studies and proposals, covering orbital and in-situ types of payloads for volcanic vents off the ocean floor, bore-holes in Antarctica, planetary surface and sub surfaces, Earth and planetary orbits, and atmospheric insertions. According to customers, The NPDT has managed to shrink development time in the early design phases by factors between four and ten.

The concurrent analysis and design method developed and implemented in the NPDT environment can with slight modifications be applied for developing spacecraft, automobiles, oil & gas platforms, and other types of large and complex systems.

1. INTRODUCTION

At the Jet Propulsion Laboratory (JPL), large resources are put into efforts aimed at improving and changing the organization to effectively deal with developing smaller missions in the hundred million, rather than in the billion dollar range. A large number of these missions are won based on competitive proposals in response to Announcement of Opportunities (AO's) from NASA headquarters. Writing and developing proposals is, therefore, becoming increasingly important for JPL.

In late 1996, it was decided that there was a need for a team that could provide early conceptual design analysis support for payload development and payload proposal work. This led to the development and implementation of the NPDT. Typically, payload or instrument proposals require high degrees of detail in their optical, radiometric, mechanical, thermal, and structural analyses. The NPDT is, therefore, utilizing what is considered high-end tools in its design and analysis work.

The NPDT can be modified both in terms of experts, and in terms of analysis and design tools. This makes it possible to provide development support for almost any type of space orbital and surface missions [1]. A design team, Team I, was spun off from the NPDT in January 2001 to focus exclusively on developing space instruments.

This paper starts with a description of the analysis and design methodology utilized in the NPDT, continues with a discussion about its implementation, and ends with some examples of how this methodology has benefited projects supported by the NPDT.

2. ANALYSIS AND DESIGN METHODOLOGY

The analysis and design methodology utilized in the NPDT was developed and refined by the author in close cooperation with engineers and scientists over the last 4 years. The methodology is based on ideas from concurrent engineering [2], and from what the author in his earlier research has termed concurrent analysis and design [3] [4]

The methodology is built up around eight central principles: (1) Analysis and design activities are performed by a multi-disciplinary design team; (2) the design team members work together in concurrent sessions; (3) "customers" and team members participate in the concurrent sessions; (4) analyses and design activities take place in a concurrent, and near real-time fashion; (5) inter-linked high-end computer tools are utilized in the concurrent sessions by the team members; (6) these high-end computer tools are used from the early parts of the design cycle; (7) common geometrical data (CAD) is shared electronically between the tools; and (8) CAD, structural, thermal, and optics data can be imported and exported to and from the design team.

Having multi-disciplinary design teams ensures that a total systems approach is taken, and that all relevant engineering and science areas are covered. Bringing the team members together in the same room for concurrent sessions makes it possible to deal with the relevant engineering and science disciplines concurrently [5]. Another interesting thing happens when the customer takes parts in these sessions. Now, requirements, which the author prefers to call input parameters, can be challenged and changed in real time, a substantial time saving. As opposed to a meeting, real analysis and design work is performed during the concurrent sessions. Using accepted high-end analysis tools for this analysis and design work, ensures that the results generated have high enough fidelity to be used directly for making trade and design decisions. The tools to be used need to be verified and trusted by the experts in every field. Having these tools interconnected, and utilizing a common geometry for their analysis and design work has made the process so powerful and efficient that this work can be done in near real-time. This means that the tools can be utilized in the 3-3.5 hours concurrent sessions. Just 5 years ago, using high-end tools for such real-time work would have been impossible. Hardware and software limitations restricted the use of these tools to high-fidelity work on point designs in the later parts of the design cycle. Introducing these tools into the early conceptual design phases improves the design quality and makes it possible to come up with high-quality designs at a point in the design cycle where people are used to seeing back of the envelope type of design quality. The use of high-end tools in the early design phases has another interesting side effect. The results, geometry (CAD) data, optics, data, thermal, and structural data can be ported to the next phases of the design cycle. There, they can be used as starting points for the refined design and analysis work required at those stages. Even more radical, since the design team is already using the same tools as are used in the later design phases, the concurrent design team might be able to support the design and analysis required also for the later parts of the design cycle. Consequently, one might be able to look at the design cycle as one process rather than a number of processes linked together. This could lead to substantial time and cost savings. The power of this approach was demonstrated for a sub-sea prototype that was brought from concept to machine shop ready engineering drawings in 3 weeks.

The utilization of a common geometry between the tools has also lead to large timesavings. For example, before, geometry was transferred manually from optics tools to mechanical tools, and from mechanical tools to the thermal, and structural tools. Each of these transfers would take some 3-5 days. Today, these transfers happen in minutes. This makes it possible to do a number of trades, analyses, and design modifications in near real-time using these tools. The last design principle emphasizes an open design and analysis environment. Being able to import and export geometry and analysis files of components, spacecrafts, launch fairings, rovers, and landers, saves time, and improves the design and analysis process in a number of ways: (1) The various components of a system can be represented more accurately. (2) Fit, orientation, fields of view, and interference issues can be dealt with more confidently. (3) Less time is spent redoing already existing, but external analyses and geometry data. NASTRAN decks would represent one such type of analysis data.

Finally, the NPDT utilizing this methodology has seen fourfold to tenfold reductions in development time and costs.

3. IMPLEMENTATION

The NPDT is a multi-disciplinary, and standing design team, that provides support to proposals, studies, and to the development of prototypes.

The initial version of the NPDT was set up to support optical instrument work [6]. Later the NPDT has expanded its capabilities to effectively be able to support the development of space payloads, space and sub-sea probes, rovers, and dedicated spacecraft. In February of 2001, an instrument Team (Team I) was spun off from the NPDT. This Team deals exclusively with space instrument development. However, to provide a full picture of the relevant interactions between the various analysis and design areas, and between spacecrafts, rovers, and, probes and their payloads both teams are discussed under the heading the NPDT.

The current set of high-end tools includes Code V ™, ZeMax™, TracePro™, MODTool, Mechanical Desktop™ (MDT), Inventor™, Thermal Desktop ™ (TD), MSC Working Model 4D™, and MSC NASTRAN™ for Windows. Most of the NPDT tools are running on PC NT platforms. NPDT currently includes analysis and design experts in the areas of UV-V-IR optics, micro- and millimeter wave optics, mechanical, thermal, structural/dynamics, electronics/power, mechanical simulations, orbital analysis, radiometry, and costing.

The NPDT environment and process is continuously being updated based on input from NPDT members and NPDT customers. In its current configuration, the NPDT includes 9 stations, a mechanical/CAD/mechanical simulation station, a thermal station, a structures and dynamics station, an electronics station, an instrument station, a radiometry station, a cost station, an orbital analysis station, and a system station. To improve group interactions, any station's display can be shown on the large projection screen in front of the NPDT room, shown in Figure 1. Often this entails importing CAD files of spacecraft, landers, launch vehicles, and specific components, to use as starting points for a design. This brings higher degree of realism into the design, and cuts down on the development time. Most CAD files are imported as STEP files. In the case of optics instruments, the optics configuration and its rays are imported to MDT from ZeMax and TracePro on the optics station as SAT and IGES files. This data is used as a basis for designing, support structures and enclosures required for the optics. Electronics, telecommunication systems, antennas, booms, radiators, etc., are also added to the design at this station. Dimensions, and masses of these components are based on NPDT analyses. From the developed design, preliminary mass, volume, and area estimates can be estimated. For mechanical design work MDT and Inventor™ are being used. At this station, true physical simulations of landers descent, rovers' mobility and stability, and strength of mechanisms to mention a few are also being performed. MSC Working Model 4D™ is used for this work.

At the **thermal station**, a combination of TD and SINDA tools is used. TD uses the geometry developed on the mechanical/CAD /mechanical simulation station together with orbital parameters for calculating orbital heating rates, and for producing radiation interchange factors. SINDA, a thermal analysis program, automatically utilizes these results, together with internal heat dissipation data for calculating temperatures on external and internal surfaces, and components. These temperatures are automatically ported back to TD and displayed on the given CAD geometry. This information is then typically used for discussions about radiator placing, and about whether active or passive cooling is required. The temperature data is also ported to NASTRAN™ via FEMAP™ for thermal deformation analysis.

At the **structures and dynamics station** NASTRAN for Windows™ is being utilized. Typically, launch loads, dynamics loads during operations, natural frequencies for booms, fasteners, supporting structures are calculated here. Input for these analyses are the MDT developed geometry (CAD), materials specs, and environmental data. Such data may be derived from simulations or from launch vehicle specifications. The thermal and structural deformations may be ported directly and electronically to the instrument analysis tools (ZeMax™, Code V™, and MODTool) for real-time structural/thermal deformation impact analyses.

At the **instrument station**, both the UV-V-IR, as well as the micro and millimeter parts of the electromagnetic spectrum are covered. The (UV, V, IR) optical designer and analyst uses variables such as number of wavelengths, aperture diameter, F#, field of view (degrees), temperature, mirror/lens surface types, and type of mirror material for designing the right optics configuration. The tools Code V and ZeMax are used for this part of the design and analysis work. The geometric representation of the surfaces of the selected optics configuration, together with the geometric representation of the resulting rays are provided as an IGES file. Additionally, the optics configurations itself can be ported to TracePro (ACIS based), also on the optics station, and turned into ACIS based solids and provided as SAT files. These SAT files can be exchanged between any ACIS based programs. MDT is one such program. Cost and mass estimates of the developed optics configuration can also be provided. The ACIS engine is developed by Spatial Technology.

MODTool a physical optics tool is used for the micrometer wave, and millimeter wave analysis. The input variables are

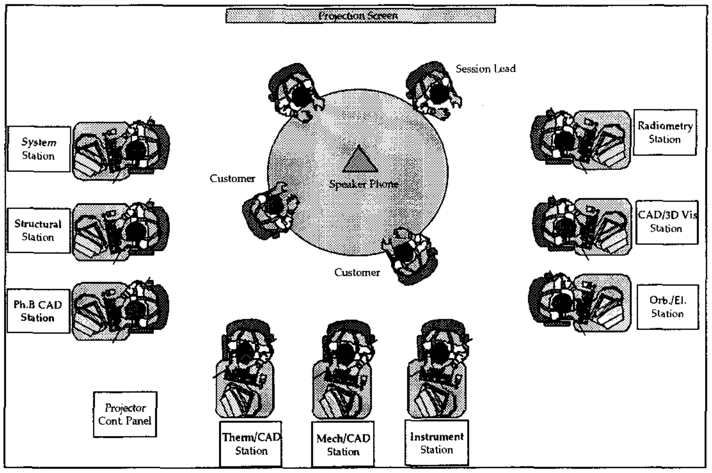

Figure 1: The NGDT Room

basically the same as those used for the UV-V-IR optics analysis. The optics configuration used for the MODTool analyses is developed in ZeMax™, and then electronically ported to MODTool. This ensures that same geometry is used for the physical optics, mechanical, thermal, and structural analyses and designs. MODTool runs on a remotely connected massive parallel computing system. Structural/thermal deformation impact analyses are performed both with ZeMax™, and with MODTool.

At the **radiometry station**, variables such as required temperature, quantum efficiency, dark current level, detector readout noise, #bits/pixel, aperture diameter, F#, spectral resolution, target scene reflectivity, altitude, number of bands, and observed wavelengths are used for calculating signal to raise (S/N) ratios. The same variables are used for calculating noise equivalent temperature (NEΔT) curves. The tools used for these calculations were developed by the radiometry analyst in Excel spreadsheets.

The work at the **electronics station** includes providing detector information for the radiometry station; defining power dissipation for the electronics components; defining electronics operating temperatures; and calculating data rates, required data storage, required, and processing power. From these numbers, a preliminary component list is put together with component dimensions, and masses and costs. Dimensions and masses are provided to the mechanical/CAD/mechanical simulation station for inclusion in the complete mechanical design. Finally, an electronics block diagram is provided.

The **cost station** is manned by a cost expert that will perform either grassroots costing (costing by analogy) or parametric costing. The parametric cost models take into account factors such as mass, type of technology, development time, and complexity of instrument part. Output from the cost station is fed into the system station.

The capabilities of the Space Orbital Analysis Program (SOAP) is used on the **orbital station** for calculating ground velocity, orbital time, sun exposure on the various sides of a spacecraft/probe, communication time between surface systems and orbiters, sun incidence angle to mention a few. The sun exposure analysis is communicated to the thermal, and optics stations helping them to place temperature sensitive detectors and radiators on the sides less exposed to the sun. For the sun exposure analysis, the common geometry developed on the mechanical/CAD/mechanical simulation station is ported directly into SOAP.

At the **system station**, the high level mission parameters (inputs) are defined at the beginning of the session. The main output variables are also sent to and displayed on this station. Some of the high level mission parameters are type of mission, type of orbit, the classical orbital parameters, orbital time (calculated), orbital velocity calculated (rad/s, and km/s); orbiting body (Earth, Mars, etc.), surface temperature and reflectivity of orbiting body, wavelengths to be observed at, and number of bands. The main output variables displayed are mass, cost, and power. Preliminary estimations of data rates and communication downlink data rates will also be calculated and displayed on the system station. The system station was put in place primarily to ensure that all applications would be using the same high level system parameters at all points in the design cycle. This is achieved by the system station making these high level parameters available to the various NPDT applications in a format that they can read. In the same way, data from the various applications are extracted from their output files and displayed on the system station. This work is under development. LabVIEW™ and C++™ are been used for developing file data extraction routines, file building routines, and routines for exchanging data between the NPDT applications and the system station.

4. SAMPLE PROJECTS SUPPORTED

Over the last 4 years, the NPDT has provided a wide range of support to a number of different types of studies and proposals. Most of these support efforts included 2-3 concurrent sessions, plus some off-line work in between them.

The team supported a design study of a 150 km fuel cell rover. For this study, the team designed, together with rover experts, the complete rover. The design started with defining the electronic box based on the electronics required for running the rover and its instruments. The frame and wheels were then added to fit with the electronics box. Inflatable wheels were used for this design. The electronics box and its internal components were made parametric, enabling quick trade studies of different configurations with solar panels and fuel cells for different roving distances. The fuel cell configuration is shown in Figure 2. A structural analysis was run on the frame geometry to confirm structural integrity during launch, landing, and roving operations. Next step was to see whether the rover would fit in the specified lander. For this, a lander model was imported as STEP file, and the rover was made to fit on it. With tires inflated, this became impossible, forcing the team to address packaging and deployment issues such as inflation sequence of tires and the need for actuators. All this was done using the NPDT mechanical tool. The rover was successfully fit onto the lander. Finally, rover deployment and roving was simulated through the porting of the rover geometry to the mechanical simulation tool. This simulation added insight into the stability of the rover during lander exit, and during surface operations. This showed that the high center of gravity made the rover somewhat unstable, especially during lander exits. However, during roving on the defined terrain stability seemed acceptable. The simulation also confirmed that the power provided for each wheel, given mass and friction coefficients, was sufficient to move the rover around on the surface, and over and between obstacles. A mass list was also provided.

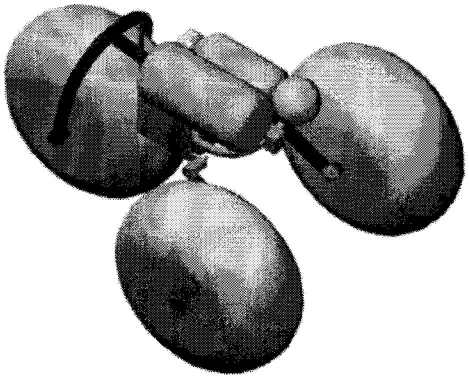

Figure 2: Mars Outpost Inflatable Wheels Rover

The team provided support for a number of payload proposals for the Europa orbiter. Ref Figure 3.

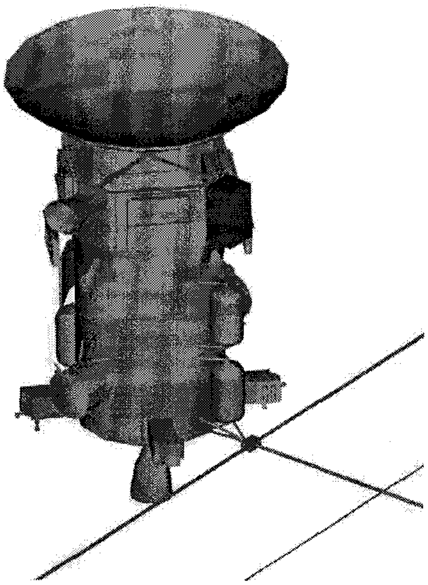

Figure 3: Payload on Europa Orbiter

To make sure that there was a clear understanding about how the payload was to be integrated onto the spacecraft, a STEP file of the orbiter correctly dimensioned was imported into the NPDT environment. This gave a clear understanding of available space on the orbiter, and potential FOV conflicts for instruments and radiators. For calculating sun exposure, Jupiter, and Europa exposure, the geometry of the orbiter and the attached payload were ported to the orbital analysis tool. Based on the analysis there, it was determined which sides were less exposed to the sun, and Jupiter. These sides were then used for placing radiators and low temperature detectors. For sizing radiators, a thermal analysis was performed based on the defined orbit, the orbiter, and payload geometries, the defined component temperatures, and the power dissipation from the electronics components. Optical geometries were developed on the optics tool, and packaging based on structural and thermal analysis results was put together on the mechanical station. The starting point for this packaging was the electronically transferred optical configuration from the optics tool. The structural analysis, included launch load analyses of mechanisms, and supporting structures. Electronic block diagrams, mass, power, data rate, data storage, and cost data were also provided.

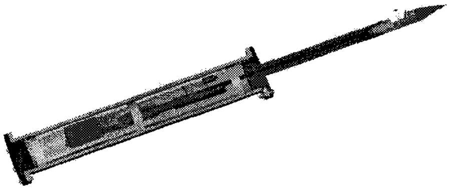

Figure 4: Lohii Type Deep Ocean Volcanic Vent Probe CAD Model

The NPDT also supported the development of a deep-sea thermal vent optical probe prototype, shown in Figure 4. The probe was designed for being inserted into thermal vents on the ocean floor, down to 8 km, looking for life forms at temperatures above 570K. The probe included visual wavelength cameras, UV spectrometers, and lasers. The front-end and back-end optics were developed by the team. The team also provided support for the packaging of electronics components, cables, and lasers, and fiber optics. This packaging effort had to juggle between very little space, and the need for easy access to optics and electronics. For this design effort, structural analyses were performed on the main housing and the thinner front cylinder of the probe. The geometry developed on the mechanical station was used as basis for these analyses. The turn-around time for this support effort was quite exceptional. Within a week, structural analyses; design of the optics, the probe, cable, and fiber-optic feed-throughs; and packaging had been completed. And, within 3 weeks, machine shop-ready engineering drawing had been delivered from the NPDT. This shows that effectively utilizing interconnected high-end tools from the early parts of the design process makes it possible to dramatically compress the design cycle, and bring a design to engineering drawing level in a very short time.

The next step would be to test this approach for larger projects, and eventually for flight projects. The probe as shown in Figure 5, attached to the front of the manned sub-marine, was successfully taken down to 1.6 km ocean depth.

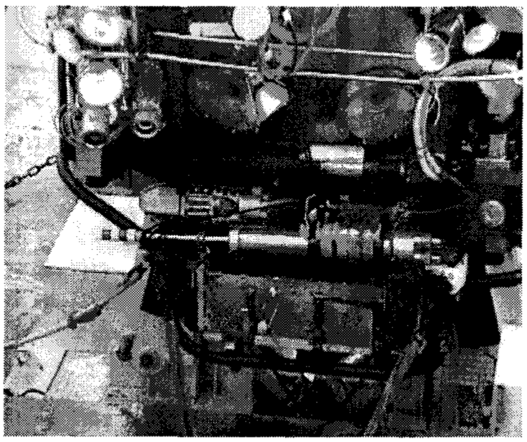

Figure 5: Lohii Type Probe Attached to Sub-Marine

CONCLUSIONS

Team members and customers are starting to see substantial quality improvements, and time and cost savings through the utilization of the design approach discussed in this paper.

The aim of the author is to bring the power of this design approach to the later parts of the design process, and test it for a larger prototype, and then for flight hardware. The author expects "unheard of" cost and time savings, similar to those achieved for the Loihi probe. Through these experiments, the author hopes to encourage his readers to look at the design process as a continuous process, rather than as a sequence of phases with high walls between them. First, when that is achieved will projects be able to reap the real benefits of this design approach.

The author is currently also studying the possibility of utilizing supercomputers and massive parallel computing systems for a number of analysis tasks in the NPDT environment. Today, only the physical optics tool - MODTool - utilizes such capabilities.

It is the hope of the author that the utilization of the NPDT methodology eventually will spread beyond the space industry, for example, to the automobile industry, helping them cut costs, improve quality, and reduce time to market.

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REFERENCES

[1] Oxnevad, K. I., "Computer Accelerated Conceptual Design Development of Spacecraft," Proceedings from the Second Lunar Development Conference: Return to the Moon II, Habitat Session, Las Vegas, Nevada, July 20-21, 2000.

[2] Oxnevad, K. I., *A Total Systems Analysis Method, for The Conceptual Design of Spacecraft: An Application to Remote Sensing Imager Systems*, Old Dominion University, Ph.D. Dissertation, May 1996, pp. 18-20.

[3] Oxnevad, K. I., "A Concurrent Design Environment for Designing Space Instruments," Proceedings from the 9th Thermal & Fluids Analysis Workshop, Ohio Aerospace Institute/NASA Lewis Research Center, Cleveland, Ohio, August 31-September 3, 1998.

[4] Oxnevad, K. I., "A Concurrent Design Approach for Designing Space Telescopes and Instruments," Paper 3356-131, Proceedings from the Space Telescopes and Instruments V Section of the SPIE Astronomical Telescopes & Instrumentation Conference, Kona, Hawaii, March 20-28, 1998.

[5] Casani, K. Thomas, N., "FST - Faster, Better, Cheaper," SPIE-94 Conference.

[6] Oxnevad, K. I., "Concurrent Design: An Application to the Design of Space Instruments," Space & Robotics 98 Conference, Track 5.2 Commercialization and Commercial Projects II, Albuquerque, NM, April 27, 1998.

Oxnevad, K. I., "NPDT The Next Generation Concurrent Design Approach," Proceedings from the Second European Systems Engineering Conference: Systems Engineering – A Key to Competitive Advantage for All Industries, Munich, Germany, September 13-15, 2000