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Integration of Cost Modeling and Business Simulation into Conceptual Launch Vehicle Design

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ABSTRACT

This paper reports on research that integrates cost modeling and business simulation into conceptual design environments for advanced launch vehicle programs. A new design-oriented computer tool has been developed and used that is capable of using price-elastic market estimates, price optimization, vehicle characteristics, and historical operations data to predict key business indicators such as return on investment (ROI), internal rate of return (IRR), maximum exposure, and break-even point (BEP). This paper includes a brief introduction to this tool called Cost And Business Analysis Module (CABAM).

In addition, this paper reports on the results of work to integrate the cost analyst, via CABAM, into the advanced conceptual design process (i.e. performance, propulsion, aerodynamics, weights, internal layout, aeroheating, etc.). Using industry standard tools and design practices within a controlled university environment, three sample launch vehicle concepts were designed with varying levels of participation from the cost analyst. Successes and difficulties in integration of CABAM are documented. Then, the resulting economic indicators are presented and interpreted for each of the three example conceptual designs to illustrate the type and range of data available. These example results illustrate the potential cost savings and increased profit generation possible when a 'design-for-business' philosophy is used.

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NOMENCLATURE

APAS	Aerodynamic Preliminary Analysis Syst.
ASDL/SRG	Aerospace Systems Design Laboratory/ Space Research Group
BEP	break even point
CA	contributing analysis
CABAM	Cost And Business Analysis Module
CCD	central composite design
CER	cost estimating relationship
CSTS	Commercial Space Transportation Study
DDT&E	design, development, test & evaluation
DoD	Department of Defense
DOE	design of experiments
GTO	geosynchronous transfer orbit
HRST	Highly Reusable Space Transportation
IRR	internal rate of return
ISS	International Space Station
LCC	life cycle cost
LEO	low earth orbit
LH2	liquid hydrogen
LOX	liquid oxygen
MLLF	Magnetic Levitation Launch Facility
NASCOM	NASA Cost Model
NAFCOM	NASA/Airforce Cost Model
NPV	net present value
PGP	profit generation potential
POST	Program to Optimize Simulated Traject.
RBCC	rocket-based combined-cycle
RFP	request for proposal
RLV	reusable launch vehicle
RSE	response surface equation
ROI	return on investment
SERJ	supercharged ejector ramjet (RBCC eng.)
SSTO	single-stage-to-orbit
TFU cost	theoretical first unit cost
TSTO	two-stage-to-orbit
$96	1996 U. S. dollars
$TY	then-year U. S. dollars (inflated value)

INTRODUCTION

In the recent decade and a half, due to international competition, the US launchers have lost a great market share in the international launch industry[1]. To compete for future payload and passenger delivery markets, new launch vehicles must first be capable of reliably reaching a number of desired orbital destinations with customer desired payload capacities. However, the ultimate success of a new launch vehicle program will depend on the launch price it is capable of offering it's customers. Extremely aggressive pricing strategies will be required for a new domestic launch service to compete with low-price international launchers. Therefore, budget constraints established by low-pricing requirements place pressure on new launch vehicles to have unprecedentedly low LCC's.

Conventionally, economic aspects of a new launch system were analyzed after a 'finalized' design concept was reached. That is, a new launch vehicle was initially designed for the lowest launch weight, lowest empty weight, or minimum fuel approach ('design-for-performance'), and then the resulting design was passed to a cost analyst who would determine development and production costs (post-design evaluation). In some cases, operations and facilities costs would be included so that the LCC could be predicted. In even rarer cases, potential markets and revenue sources were considered so that a cash flow stream could be predicted. This last level of information, while rarely provided, comprises the minimum needed to evaluate the potential commercial business viability of a new launch service.

Unfortunately, for conventional design methods, the highest performance vehicle is seldom the lowest cost vehicle. In fact, even the lowest development cost vehicle may not necessarily be the most attractive vehicle from a commercial business and profitability viewpoint. If a decision maker's objective is to produce a system with a high profitability and low financial risk, then there must be a way to estimate cost and business indicators early in the vehicle design process and a mechanism to feed cost and profit information back into the actual design process. This would enable cost and profit management from the earliest design stages. Such a capability could change a 'design-for-performance' principle into a more desirable 'design-for-business' principle within advanced design organizations.

Implementing a 'design-for-business' principle during the conceptual design phase has two requirements. First, a new design-oriented cost and business simulation model must be available. The model must be reasonably fast, accurate, robust, and capable of operating on data of the detail typically available in the conceptual stage of design. Second, cost modeling and business simulation must be fully integrated into the conceptual design process. The business/cost analyst must also be knowledgeable in engineering aspects and become a full member of the design team. Then, each vehicle design cycle must include a prediction of key business indicators, and each design decision should be made with full knowledge of its impact on those indicators.

COST AND BUSINESS ANALYSIS MODULE

Overview

CABAM is a tool for unlimited 'what if' analyses and program cost assessments for the entire life cycle of new launch vehicle concepts, which aids decision making and design optimization. CABAM bases all such related analyses on fiscal units (US$) whereas there has been achievements in cost analyses of similar sort based on labor metrics (men-hours)[2]. It is a multi-spreadsheet economic analysis tool capable of generating annual figures for all major LCC contributors and expected annual revenues. Summary business indicators such as IRR, NPV, maximum exposure, ROI and annual and cumulative cash flows are determined for each design concept. CABAM currently runs under Microsoft Excel, a platform which allows easy output formatting, easy expansion of results, and quick production of plots and tables for enhanced decision support. CABAM is an improvement and extension of earlier cost modeling work[3] and is a public model available on request from the authors.

CABAM requires vehicle component weights, vehicle payload capability, and a set of economic and market assumptions as inputs. For each vehicle design, the cost analyst is also required to make subjective adjustments to the life cycle cost model as necessary - technology complexity factors, reusable hardware life spans, operations cost adjustments, additional facilities requirements, etc. Business schedule factors such as vehicle acquisition plan, vehicle operation plan, financing, and management of liability accounts are also under the analyst's discretion.

A schematic of the internal structure of CABAM is shown in Figure 1. CABAM has two main information flows. The first is a 'cost' stream of information that includes non-recurring costs (DDT&E, reusable hardware production, and facilities construction), recurring costs (operations/maintenance and expendable hardware production) and financing costs. The second information stream is a 'revenue' stream. Annual revenue is derived from launch prices, market elasticity, and flight rates. The two information streams are combined to create annual cash flow which, in turn is used to determine IRR, NPV, cumulative cash flow, and other business-oriented indicators that represent the program's PGP.

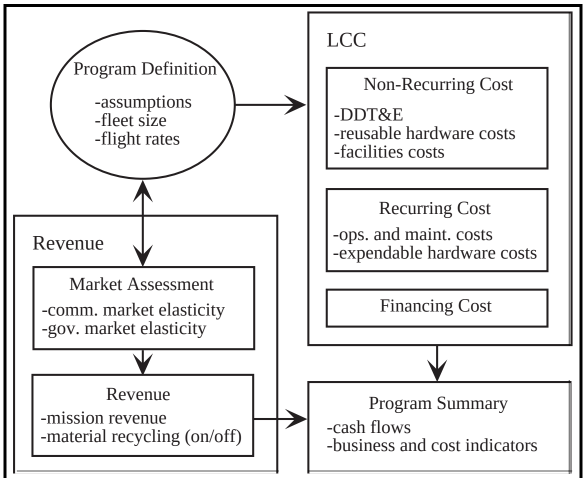

Figure 1: Internal Structure of CABAM

LCC Assessment

Within CABAM, various estimation methods are used for assessing the LCC. When baseline operation and acquisition schedules are specified in the Program Definition sheet, the vehicle design is entered via payload capabilities, system component weights, and complexity factors in the DDT&E & TFU module. The only shared information between the LCC and revenue streams is the flight rate (flight rates are actually derived from the revenue stream initially). Via this connection, LCC and revenue data are linked and made consistent.

To begin the non-recurring cost estimate, DDT&E and TFU costs for reusable system components are estimated using weight-based cost estimating relationships (CERs) by a major subsystem breakdown. A typical CER is in the form of below.

$$\$ = C_f * A * W^B \qquad (1)$$

Here, W is the component weight, A and B are system component-specific constants and C_f is the complexity factor that is a combined measure of mechanical and material technology concerns. The A and B values are derived from the unrestricted-release version of NASCOM database (a newly released version has been renamed as NAFCOM)[4] for similar hardware systems. When the reference 'first unit' TFU costs are determined, learning and rate effects are imposed for subsequent system acquisitions. Currently, the next non-recurring cost component, the facilities cost, is estimated by a stage-associated cost allotment scheme. For a given vehicle design, an amount of facilities cost for each stages is reserved for expenditure. For special facilities such as ground launch assist, when included, a separate specific cost inclusion is made. Currently, stage-specific facility cost estimates must be input by the analyst.

Expendable system acquisition cost is estimated in the same manner as reusable systems (by CERs) and is accounted for under recurring cost. Another major recurring cost contributor, which is the most challenging to predict, is the operations and maintenance cost. It is estimated as a sum of total labor costs, hardware refurbishment costs, and propellant costs[5]. CABAM has a function of ground crew requirements vs. flight rate that is defined by the user and drives the labor costs. This function simulates additional hiring when flight rates become too heavy for a certain work crew to handle. This emphasizes the real-life business practices where the work crew requirements as a function of flight rate is not a continuous one. Airframe/hardware insurance costs are also included in recurring costs as a user inputted percentage of expected financial losses per flight.

The final major component of LCC is the financing costs. Due to large capital requirements in typical launch system programs, financing is a significant factor that affects LCC. CABAM has a built in capital financing scheme that is based on corporate bonds. Debt-to-equity ratio, bond terms, payment schedule on liability are some of the related inputs a cost analyst must provide. CABAM displays annual figures for accumulated liability obligations, payments, and interests for the cost analyst to plan a financing strategy. BEP and maximum exposure are extremely sensitive to the financing strategies.

Government participation is another factor that plays a major role in modern launch programs. NASA assists commercial entities usually via cooperative agreements that provide financial and other aids (e.g. the X-33 and the original X-34 cooperative agreements). In CABAM the commercial burden of LCC can be lessened to a degree by government contributions and provisions. CABAM has specifiable government contributions in DDT&E, hardware acquisition, facility, and operation and maintenance costs that the cost analyst can input separately.

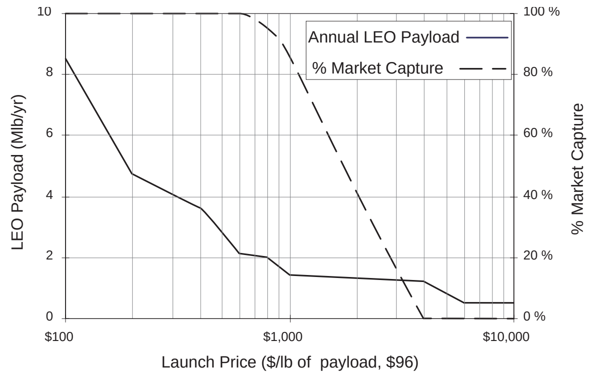

Figure 2 - LEO Cargo Market

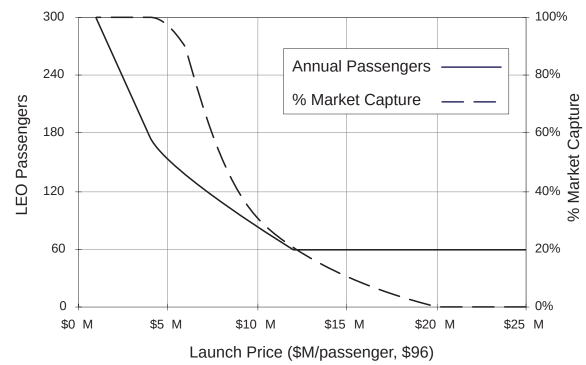

Figure 3 - LEO Passenger Market

Revenue Assessment

Revenue is ultimately a function of launch *price* in CABAM. The nature of any profit-driven ventures requires pricing strategies that invariably follow price-elastic markets. The market size and share will depend upon the price of the launch service. In CABAM, these market elasticity curves for various future launch markets were derived from NASA's Commercial Space Transportation Study (CSTS) study[6]. Sample markets for Low-Earth Orbit (LEO) payload and space station missions are shown in Figures 2 and 3. CABAM considers competition for the market by imposing a market capture percentage on the total market sizes. Captured market size and available payload dictate annual flight rates. Flight rates and launch prices are then used to calculate annual revenue. Vehicle fleet size is a function of both airframe life and vehicle turnaround time. Vehicle turnaround time is usually checked after a simulation for its viability. Currently, the Shuttle turnaround time is 125 days and for the RLV and HRST, 12 and 2,5 days are estimated as viable (based on an average 7-day mission)[7].

The current version of CABAM (v. 5.0) includes separate launch prices for commercial and government missions and, for each, separate market elasticity curves for up to four future market classes — LEO cargo, LEO passengers/ astronauts to International Space Station (ISS), GTO cargo, and high speed global point-to-point missions. In this modeling scheme, a set of pricing for each target market are the true input variables for CABAM and are the independent control variables that can later be optimized for highest profit.

An unique revenue component in CABAM is a 'material recycling' option. As with old commercial airplanes, when a launch vehicle is at the end of its life span, it is declared inoperable. In such an event, the exotic materials that were used on the vehicle can be ‘scrapped’. This is built into CABAM as a toggle option that a user can decide to include as another source of revenue at the end of each launch vehicle’s life span. Only the body, wing, and tail materials are considered for recycling for this purpose. In a large fleet of reusable launch vehicles, this material recycling option yields a rather substantial effect on the program economy.

Economic Indicators

Key business indicators are the major outputs of CABAM. The most important indicator is the IRR. It is a generally accepted measure of the programs total economic performance in profitability. NPV shows how the program fared against a prescribed discount rate. ROI shows the relationship between the profit and actual capital investments made. Maximum exposure is recognized in CABAM as the minimum point in the cumulated cash flow, and represents the risk associated with making the initial capital investment. In addition to those business indicators above, there are additional cost indicators such as recurring cost per flight and LCC per flight that help understand the focal points of profit generation. By determining these cost indicators, the markets to attack most aggressively can be determined.

These indicators are measures that reflect the entire launch vehicle program’s economy. Overall assessment of a program requires careful evaluation and consideration of all of the variables. CABAM’s spreadsheet environment allows fast generation of analytic plots and tables for this purpose.

Business Simulation

After all the inputs are entered into CABAM, there are several steps to simulating a business operation with the designed launch vehicle. A summary of inputs, outputs, and a general post-simulation analyses sequence is illustrated in Figure 4. The first and the most important step is to optimize launch prices for each of the target markets. A given design may be more effective in certain markets yet miserably fail in others depending on the pricing and the mission-specific costs. Therefore an optimization for overall profitability must be done on the launch prices. Maximizing IRR (calculated for an after-tax discounted cash flow) is the objective used in all of the examples reported in this paper. Limited local optimization is readily available via a built-in gradient-based optimizer in Excel called ‘Solver’. However, many of the internal variables and inputs for CABAM are discrete integers. As a result, the optimization space is highly non-smooth. The gradient-based Solver tends to become trapped by the nearest local minimum IRR and is not suitable for global optimization. Several global optimization strategies have been successfully overlaid onto CABAM for price optimization. For example, coarse grained exhaustive grid searches have been implemented through a Microsoft Visual Basic program and a remote execution of CABAM (for a workstation-class computer) using Applescripting techniques. Once a favorable price region is found, Solver can be used to find the optimum.

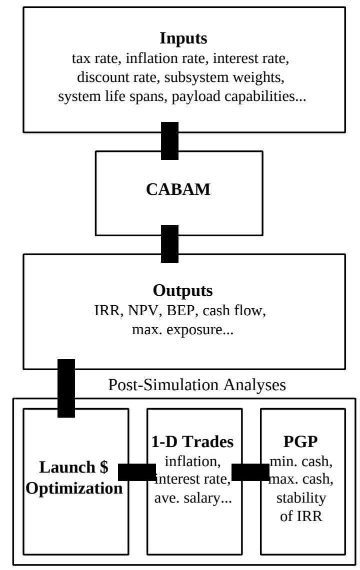

Figure 4: Input, Output, and Post-Simulation Analyses

The second step in the business assessment is to check for the performance of the program economy under possible fluctuations of input assumptions. These uncertainties can include corporate tax rates, inflation rates, average salary for work force, and even market sizes themselves. To be certain about a launch system’s PGP, stability of IRR must be checked against fluctuations in these uncertainty variables, since these rather crucial assumptions generally have great effects on the program economy. CABAM can quickly perform these 'what-if' analyses and report associated IRR fluctuations as long as the uncertainty problem can be studied as a one-dimensional fluctuation. To truly test the program's performance under multiple economic uncertainties, a structured approach is necessary.

APPLICATIONS IN CONCEPTUAL DESIGN

To demonstrate the integration of cost and business analysis into a traditional conceptual design process, CABAM was placed into a multidisciplinary environment of traditional design codes (i.e. propulsion, performance, aerodynamics, weight estimation). Since CABAM depends on the major subsystem weights of a candidate vehicle design, it is executed after the weights have been converged between the other disciplines. Design payload capacity, system life spans, and the economic and business variables are then set. As the vehicle subsequently changes during the design optimization cycle, only the subsystem weights typically need updating. The economic and business variables are usually set by preconceptual information and should not need to change as the vehicle size changes.

Examples of integrating cost and business analysis modeling into the conceptual design process with CABAM, in different degrees, are visible in the next three launch vehicle designs.

Cerberus

The concept 'Cerberus' is shown in Figures 5 and 6[3]. Cerberus is a TSTO launch vehicle with initially planned capabilities to service both the LEO and the Geo-Transfer Orbit (GTO). Its first stage booster utilizes seven supercharged ejector ramjet (SERJ) RBCC engines. Second stage systems have two variations of which one is designed for LEO cargo and passenger missions (to ISS) and the other for GTO missions. Both are shaped as 'waveriders'. In addition, the booster could be configured to serve global high speed point-to-point delivery markets for volatile substances and pharmaceuticals. High technology requirements and the corresponding readiness level

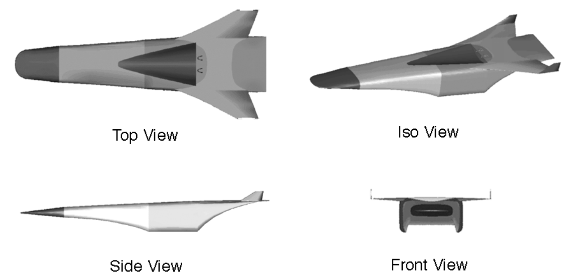

Figure 5: Cerberus Booster Configuration

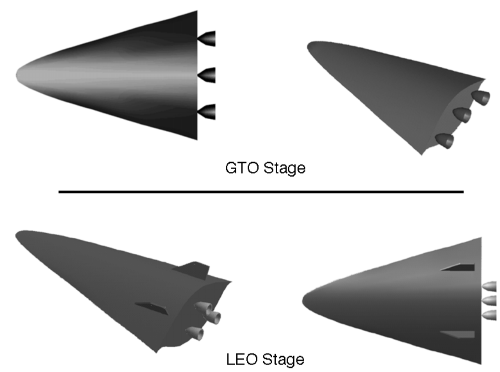

Figure 6: Cerberus Upper Stage Configurations

force the initial operating capability (IOC) to be at year 2008. Steady state operation period is planned from years 2010 to 2025.

Several independent Cerberus system 'point designs' were created in an effort to explore the design space. Key variables were varied between the concepts such as staging Mach number, upper stage engine, and upper stage airframe material. These variables were anticipated to have an effect on vehicle weight, performance, cost, and economic return. For each converged point design, CABAM was used to select optimum prices for each of the four markets. A subsequent 'best-of-the best' comparison was then made among the candidate designs to select the one with the highest potential IRR (a Mach 8 staging, staged combustion LOX/LH2 upper stage engine configuration).

The economic evaluation yielded a surprising result which, after the launch price optimization, CABAM chose not to operate in the GTO market. The launch price optimization process chose a launch price (a very high price) for GTO missions that would capture zero market share. The reason was that the GTO stages were expendable systems and the cost incurred by acquisition of these expendable stages was overwhelming the entire program economy. This was a good example of early economic analysis saving future DDT&E costs. All system design decisions were re-focused on reducing the GTO stage's system acquisition cost, yet for the program's profitability, the GTO stages were eventually abandoned. This is illustrated in Table 1. The annual and cumulative cash flow diagrams for Cerberus are shown in Figure 7. In a cash flow diagram as such, BEP, maximum exposure, and cash flow trends are the important information that a cost analyst should focus on.

Table 1: The Effect of Expendable GTO Stages

	without GTO	with GTO*
IRR (%)	19.59	10.66
Maximum Exposure ($TY,M)	1,782	2,736
ROI (%)	287.07	67.81
Total Revenue ($TY,M)	55,151	60,018
NPV ($M)	-99	-249

** 2 GTO missions per year @ $14,000/lb.*

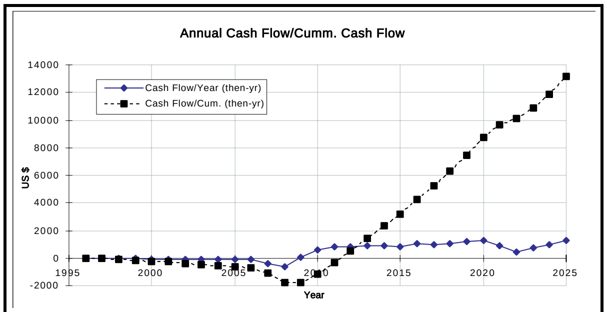

Figure 7: Annual and Cumulative Cash Flows of Cerberus

Though this design process was very similar to a more traditional process of assessing vehicle cost after a point design has already been converged, there are two significant differences. First, the speed in which CABAM can be executed (minutes) allowed the designers to consider the economic value of several different vehicle options. Traditional cost estimates typically take days or weeks. Two, CABAM was used to not only assess cost, but also revenue and IRR.

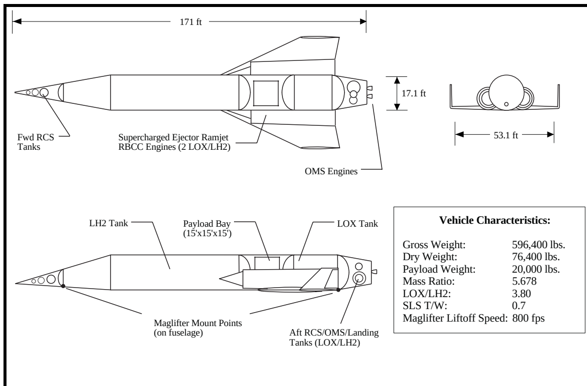

Figure 8: Argus 3-View

Argus

The 'Argus' concept, Figure 8, is near completion at the Georgia Tech ASDL/SRG[8]. The basic premises that have been established are SSTO, launch assist via Magnetic Levitation Launch Facility (MLLF), and cargo and passenger service to LEO. One of the goals of the Argus project is to observe the advantages of launch assist. The IOC was projected to be at 2008 and steady state operation period was assumed to be from year 2010 to 2025.

Argus is being studied as part of the NASA's Highly Reusable Space Transportation (HRST) study. One of tenants of the study is that low recurring costs are achievable by taking advantage of market elasticity at lower prices while still maintaining a program that is economically profitable. Therefore, the use of a tool like CABAM became imperative. CABAM is capable of evaluating recurring costs per lb. of payload while simultaneously selecting market prices to maximize IRR. For Argus, separate government and commercial price elasticity curves for each of the two markets considered (for a total of four different price points)

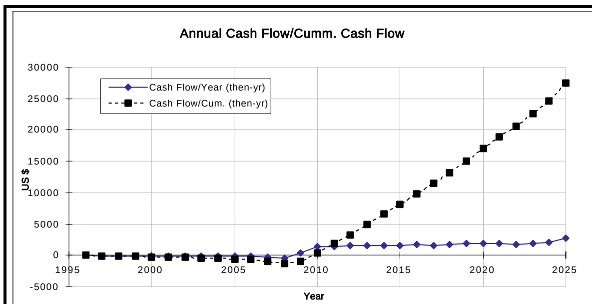

Figure 9: Annual and Cumulative Cash Flows for Argus

For the baseline Argus concept, business analysis results show an optimum IRR of 27.8% at a very low launch price for LEO payload missions of $845/lb. This is a considerable improvement in lowering launch price and can even stimulate market growth for the entire launch industry. The resulting cash flow diagram is shown in Figure 9. When finalized, the Argus concept will be a strong HRST candidate for future launch options.

Sirius

The 'Sirius' concept was developed to launch a hypothetical constellation of LEO satellites. It is a TSTO, vertical take off, horizontal landing launch vehicle capable of servicing Mega-LEO class constellation deployment. Figure 10 shows a 3-view

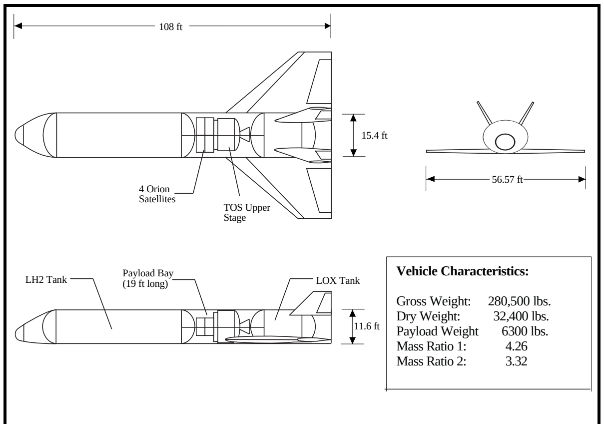

Figure 10: Sirius 3-View

of the Sirius booster stage. The planned IOC for Sirius was year 2002. Therefore, involved technology levels were limited to current levels[9].

The Sirius launch system was developed in response to a hypothetical request-for-proposal (RFP). The RFP demanded a launch system that can deploy a 400 satellite constellation (borrowing the name '*Orion*') in a 2 year period. Therefore, Sirius was targeting a non-elastic market that limited revenue generation to a $3M ($96) per satellite basis. A constellation replenishment period of 10 subsequent years following deployment was planned at 20 satellites per year with the same launch price which provided a total program revenue of $1.8B ($96).

To achieve low-cost, high flight rate, fixed revenue operations, a TSTO concept was chosen from a brainstorming process by the design team members. Several design variables were proposed for evaluation. The booster stage was to use one of three currently available propulsion systems and the second stage one of three currently available solid motors. Other design variables were booster airframe material, booster fineness ratio, and number of satellites co-manifested on a single launch. To evaluate the numerous possible combinations of these design variables, a two-phase design strategy was developed: first generate a response surface equation (RSE) for each major design discipline including CABAM and then use a genetic algorithm optimizer to optimize the design based on those RSEs to finalize the design variables.

To emphasize the importance of economics in complying to such requirements, the objective function for the optimization process was chosen as the IRR. That is, the entire vehicle design and selection of design features was performed to maximize IRR. This is one of the few examples of a 'design-for-business' philosophy being applied in conceptual launch vehicle design.

It was found that to integrate CABAM into a design iteration loop, only the weights and sizing CA needed coupling. Propulsion systems were purchased, instead of being developed and manufactured, and the final configuration selected the Russian RD-0120 main propulsion system and Transfer Orbital Stage (TOS) upperstage motors out of several existing propulsion system choices. A tether deployment system was chosen as the orbit installation mechanism and each cost $60,000. Each TOS motor carried 4 satellites and a tether deployment system as payload[10].

The final Sirius design was able to meet the requirements and generate a positive IRR of 1.11%. Even though well below a commercially viable standard, by reaching a positive IRR, the design efforts have proven that the goals can be met for this fixed low budget problem. Among the various post-simulation analyses, the effects of expanding to LEO markets other than the *Orion* constellation and the resulting generation of a PGP envelope are noticeable. To be more realistic in business assumptions, it was decided to operate the Sirius launch system for other

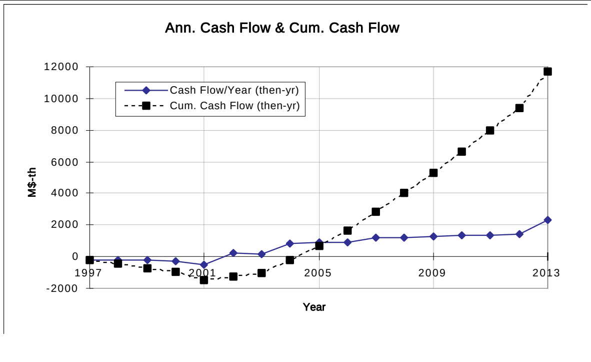

Figure 11: Annual and Cumulative Cash Flows for Sirius with Maximum Market Coverage

payloads to LEO by assuming an elastic market profile and a separate launch price. The resulting cash flow diagram is shown in Figure 11. Assuming a market coverage of 100% of the available market predicted (that is, the flight rate allowed to go to the maximum predicted by the elastic model) the IRR was improved to 28.9%. Realistically, this maximum market expansion may be unreachable, since the management may feel reserved to increase the scale of the program economy by 2.5 fold (LCC of *Orion*-only: $1,943M ($96), maximum market: $4,907M ($96).

From various business strategies related to a launch vehicle program, maximum and minimum profit generation scenarios can be used to generate a PGP envelope. For Sirius it is as seen in Figure 12. This PGP envelope is important to the program management, since it reflects general growth potential of the launch program relative to a baseline business scenario. For a poor launch vehicle program, the PGP envelope gives a flatter profile over the same amount of time scale. When the best scenario is considered

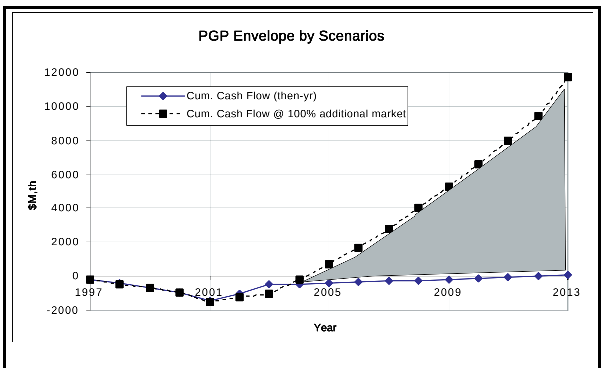

Figure 12: PGP Envelope for Sirius Business Scenarios note: gray area represents the PGP envelope

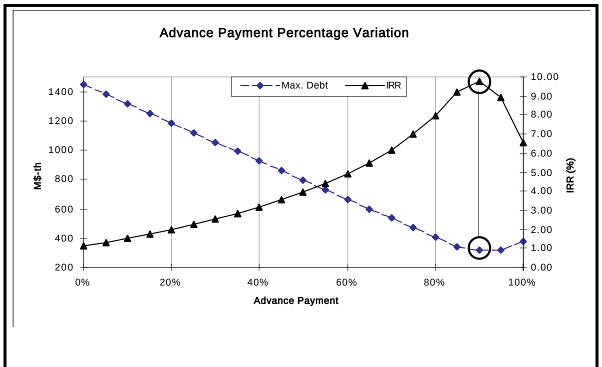

Figure 13: Advance Payment Trade Study for Sirius

reasonable, the launch vehicle program with larger PGP envelope area is generally the better one.

As a demonstration of post simulation analyses, a plot of assumable advance payment is shown in Figure 13. The underlying premise was to require the *Orion* constellation to pay a fraction of deployment fees in advance. The resulting IRR and maximum exposure shows that the optimum amount of advance payments is not a 100%. Interestingly, for Sirius, the combined effect of investment tax credits and interest rate gave the most benefits at 90%.

The non-smooth nature of LCC and business analysis modeling is clear in Figure 14. It was mentioned that a full commercial market coverage in addition to the predefined *Orion* constellation deployment was a possibility. In such a case, additional units of Sirius boosters must be purchased for the drastically increased flight rates. It is clearly visible in Figure 14 that recovery from those additional booster purchases are resulting in peaks of increased optimized launch prices as more additional market coverage is assumed.

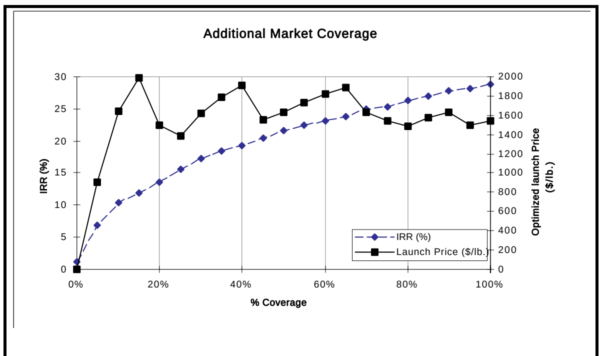

Figure 14: Additional Market Operations of Sirius

Table 2: Concept Comparison

	Cerberus			Argus		Sirius	
Markets	LEO-PL	LEO-ISS	HS-PTP	LEO-PL	LEO-ISS	*Orion*	LEO-PL
Payload (lb.)	10,000	8 pass.	100	11,100	6 pass.	6,000	6,000
Max Flights/yr.	43	2	18	93	10	50	126
Launch Price ($/lb.)	1,355	1.2M/pass.	3.87M/trip	845	0.51M/pass.	2,000	1,547
Max IRR (%)		19.59			27.8	1.11	28.88
Max Exposure ($TY, M)		1,782			1,306	1,445	1.482
Ops. $/lb. Payload	131.2	-	39.4	99.4	-	117	117

Comparison

Table 2 summarizes the key results produced by the three example applications. Argus and Cerberus results are price optimizations of a given point design (although the Cerberus design is the best IRR from several candidate designs). Argus shows the lowest price per pound of the concepts. This is largely a result of the long life airframe (1000 flights) baselined for the HRST study. Of the three concepts, Sirius is the only one specifically optimized for maximum IRR (all design variable, not just market prices). It also had the smallest payload capability and, naturally, the highest flight rate and fleet size.

In the authors' economic modeling experience, the smaller payload and higher flight rate vehicle programs often outperform higher payload and lower flight rate vehicle programs. There are several factors that seem to influence this result. One, the smaller vehicles have lower DDT&E and TFU (fleet acquisition) cost. Therefore, non-recurring costs are less. The fact that that these non-recurring early costs appear early has a very significant effect on IRR. In addition, the lower non-recurring cost means that more of each flight's revenues can be used for profit. Also, the smaller vehicles have advantages in recurring costs (operations) to their smaller size and more efficient use of ground labor. Other benefits of having a smaller, high flight rate vehicle are that the maximum exposure (the most negative cumulative cash flow) is smaller and financing costs are more manageable.

CONCLUSIONS

The examples presented show some of the results than can be realized when cost and business modeling is integrated into the conceptual launch vehicle design environment. CABAM is a very effective tool when carefully used for this task which invariably requires an addition of an economics analyst to the conceptual design team.

A final thought is given to an urgent need of a universal measure of a 'good' economic performance. Some efforts have been present, yet there is a need for a standardized economic performance measure for every launch vehicle concept. Measures such as profitability, financial risk, and technology readiness risk should be represented in the new metric. The presence of an overall metric will greatly help any decision maker's judgment for comparing different launch vehicle concepts, and therefore eventually ensure a better execution of a launch vehicle program.

FUTURE WORK

Certain modules within CABAM will continue to receive improvement. In particular, the current facilities cost module is extremely limited. Improvements in the operations and maintenance module is also a priority.

Currently, there is success in automatically running CABAM via telnet operations as a local job within a workstation-based automated design integration environment. Refinements in this integration method will save time and greatly enhance the launch price optimization process and ultimately, the entire conceptual design process. The ultimate goal is to create a tightly-integrated automated design framework on a geographically widely-distributed network of heterogeneous computing platforms.

For the uncertainties associated with economic variables such as inflation rate, there is a strategy being studied incorporating Monte-Carlo simulation techniques. This structured approach toward uncertainties will allow the assessment of risks associated with launch vehicle program's economic performance.

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