



THE UNIVERSITY OF TEXAS

AT AUSTIN

Department of Aerospace Engineering and
Engineering Mechanics

Orbital Mechanics Seminar

Bill Clark

ASE Graduate Student

The University of Texas at Austin

Earth to Mars Trajectories Using a Four Body Model

Numerical optimization of the actual April 2001 mission as a Four Body Problem generates a new trajectory that takes 30 days less than the minimum energy Hohmann Transfer, using the same total thrust. It's "faster and cheaper" . . . and "safer" too! The efficient construction and optimization of this solution is made possible by a unique two-body mapping. The presentation will include a new methodology for this fast mission profile as well as a short discussion of the Four Body Problem when restricted to this quasi-Hohmann transfer.

Thursday, November 2, 2000

WRW 113

3:30–5:00 p.m.

For further information please contact Cesar Ocampo,
WRW 412B, phone 471-5696



DEPARTMENT OF AEROSPACE ENGINEERING AND ENGINEERING MECHANICS
THE UNIVERSITY OF TEXAS AT AUSTIN

#3

Austin, Texas 78712-1085 • (512) 471-7593 • FAX (512) 471-3788

October 15, 2001

Bill Clark
21203 Paseo De Vaca Street
Lago Vista, TX 78645-4941-03

Dear Bill:

For some reason, I am no longer able to communicate with you by e-mail. My messages are returned (the email address I have for you is center4cm@earthlink.net). Below are two messages I sent to you Friday and today.

Under Aerospace Engineering, the Graduate Catalog says that a student is making satisfactory progress toward the PhD degree if he takes courses during the first year and takes the Written Qualifying Exam at the end of the first year. You have been in the program for four years and just this summer took the written exam. It is also the policy of the ASE Graduate Studies Committee that students take the Oral Qualifying Exam soon after taking the written exam, at least during the next semester. As a consequence, I am expecting you to take the Oral Qualifying Exam before the beginning of the spring 2002 semester. You will not be allowed to register for another semester until you do so.

The research part of the PhD in ASE must be carried out under the supervision of a faculty member on the ASE Graduate Studies Committee. When that faculty member is satisfied that you have done a good piece of research, he will allow you to write a dissertation and present it to your committee.

Until you begin to follow the procedures of the program, all the work you are doing independently of the faculty will not get you a PhD degree. Dr. Fowler has indicated that he would be willing to work with you. Until you associate yourself with him in a manner which is satisfactory to him, nothing will happen.

I am also expecting you to come to my office at your earliest convenience to discuss what is expected of you in the completion of the PhD degree.

Sincerely,

David G. Hull

Prof. David G. Hull
Chairman, ASE Graduate Studies Committee

Xc: Dr. Wallace Fowler



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THE UNIVERSITY OF TEXAS AT AUSTIN

Austin, Texas 78712-1085 • (512) 471-7593 • FAX (512) 471-3788

December 14, 2001

Mr. Bill Clark
21203 Paseo de Vaca Street
Lago Vista, TX 78645

Dear Mr. Clark,

Per your request a committee of graduate faculty in the orbital mechanics area was formed to review the research project "Mars Path Finder" that you submitted to us for review in November 2001. Since you failed to attend the meeting with Dr. Dolling and me on December 11th 2001 to discuss the committee's review I am conveying to you the findings of that review, and our subsequent actions, by this letter. The committee's judgment was that the work was inadequate for either a dissertation or thesis. Further, none of the faculty in the orbital mechanics area is willing to serve as your advisor or on your research committee. Since an advisor and research committee are essential elements of the doctoral program, and no faculty members are willing to serve in such a capacity, you cannot continue in the doctoral program. You will not be permitted to register in the aerospace engineering graduate program for Spring 2002, or thereafter. The oral examination scheduled for December 18th has been canceled. These actions have been approved by the Vice President and Dean of Graduate Studies.

Sincerely yours,

David G. Hull

David G. Hull, Graduate Advisor (ASE) and Chair of the ASE Graduate Studies Committee

DS Dolling

David S. Dolling, Chairman, Dept. of Aerospace Engineering & Engineering Mechanics

DSD:tw (D473L)

C: Teresa A. Sullivan, Vice-President and Dean of Graduate Studies
Ben G. Streetman, Dean, College of Engineering
Neal E. Armstrong, Assoc. Dean for Academic Affairs

11/25/01

Subject:

Review of Mr. Bill Clark's Work Concerning the Optimization of Earth to Mars Trajectories

Mr. Clark presents a method and its associated computer algorithm to optimize ballistic trajectories from the Earth to Mars. He claims that his solution is both faster and more efficient than the well known Hohmann-type transfer used in preliminary mission studies. Specifically, he claims that his solution is 20% more energy efficient and one month shorter in transfer time duration than the well known Hohmann type-transfer.

There are serious problems with his method, his assumptions, and the description of the method.

First, we list a series of comments, assumptions, and claims present in his written presentation:

1. Mr. Clark uses the term 'optimize' freely, ambiguously and without a clear explanation of what exactly is being optimized. At one point, he does mention that a composite cost function that includes transfer time and delta-v cost is the objective function, but he never presents the method of how exactly this cost function is extremized. It seems that he solves a 'targeting' problem and then computes the cost, claiming that it is in fact a minimum. This claim has no basis.

Comment:

There exists an enormous body of work associated with trajectory optimization for all types of propulsion systems. The methods in this body of work are fundamentally based on such general topics as optimal control theory, functional optimization, nonlinear parameter optimization. These methods have been applied to all types of force models and propulsion systems. Mr. Clark makes no mention of these known methods and techniques. If he is attempting to present a new and revolutionary method to this problem, he has failed because no description is present anywhere in his documentation.

2. Mr. Clark states that his program uses the J2000 ephemerides, which is taken to be the JPL based planetary ephemerides, to obtain the positions of Earth and Mars in his simulations. However, his model, as he claims, makes the assumption that Earth and Mars are in circular and coplanar orbits about the Sun. If this is so, then there is no need to mention that the JPL ephemerides are used because they are not. Based on his description, he uses the ephemerides to compute the initial relative position of Earth at Mars at the starting point of his simulation. Thereafter, they are no longer used. If he claims that his solution is both faster and more efficient, and that it can be used for actual mission design, then his claim has to be invalid because it is not based on a realistic force model.
3. His claimed solution is based on 5 distinct impulsive maneuvers (which he describes as 'thrusts'). Two of these maneuvers are near the Earth, one is in deep space, and two near Mars. The fact that the trajectory is 'forced' to be based on 5 deterministic maneuvers immediately constrains the solution and precludes the existence of solutions that require

less maneuvers. There exist well known techniques based on optimal control theory to determine whether additional maneuvers are required and optimal. He makes no mention or use of this and arbitrarily assumes a 5 impulse trajectory. It is possible to achieve an Earth-to-Mars transfer with a minimum to two maneuvers; in fact this applies also to a transfer that takes the spacecraft from a low Earth orbit to a low Mars centered orbit. Practically, however, additional correction maneuvers are needed in a real force model but deterministically, only two maneuvers are sufficient.

4. He claims that the theoretical basis for his method or program is based on the Fourier Series expansion of the motion of the planets about the Sun. This statement has no basis here and in fact he does not elaborate and justify his claim. He introduces completely irrelevant statements associated with both the 'Regularized Elliptical Three Body Problem', and 'rotational relative motions between inner and outer planets' and postulates that similar dynamics are present near Mars and that this 'may be a reason' (sic) for the fast and efficient trajectory he has found.
5. Mr. Clark presents a two page paper titled the Restricted Four Body Problem. This two page exposition is nothing more than the description of a Hohmann-type transfer from Earth to Mars in different coordinate systems. The first is a Sun-centered frame, and the other frames are a spacecraft centered frame, an Earth centered and Mars centered frame. Though he claims that the Earth and Mars centered frames are 'rotating', based on the plots he presents as an addendum to his 2 page paper, it seems that these are just fixed non-rotating frames that revolve about the Sun. Nevertheless, trajectories assume very non-intuitive paths in rotating frames, and Mr. Clark attempts to claim that some of these interesting dynamics is a 'phenomenon'. He ends his paper with two paragraphs with irrelevant and disconnected claims: The first is that the graphs show that a maneuver should be applied at conjunction (where both Earth and Mars lie on a line on the same side of the Sun). Secondly, he claims that a 'proof' of this theory is based on the fact that new subatomic particles discovered in physics are not new, but exist only briefly on a zero velocity curve. There is no scientific basis for this statement.

Analysis of the Results of Mr. Clark's Mars Pathfinder 2.0' Program.

Mr. Clark has written a program to compute a 5 maneuver transfer from a low 200 km orbit about the Earth to 100 km altitude orbit about Mars. His program assumes circular and coplanar orbits for Earth and Mars and the trajectory also lies in this same plane.

He describes in a very ambiguous way the process used to arrive at a solution. There are so many inconsistencies in this description, that only the most inconsistent will be mentioned.

1. The capture maneuver at Mars should place the spacecraft in a circular orbit around Mars as specified by the user as the final orbit. For this maneuver to be efficient, it should be applied in a direction that is tangent to the incoming orbit. Therefore, the incoming trajectory should have a close approach to Mars where the radius of this close approach must equal the radius of the circular parking orbit. This is known. However, Mr. Clark refers to this incoming trajectory as a special type of 'free return' trajectory; what he

means by this is simply that that a free return trajectory about Mars is similar to a free return trajectory from the Earth to the Moon where the spacecraft has a close approach where the velocity vector perpendicular to the orbit radius vector from the Moon or Mars. I.e., he uses a completely irrelevant description of the type of incoming trajectory that needs to exist at Mars. Further, he claims that the program attempts to find a free return in the Mars-Sun system; but a free return to where? He does not say.

2. He claims that his approach provides a total savings in delta-v of 5km/s; a savings of 20% over the 'typical flight allowance'. This is where he gets his 20% figure; clearly the difference between circularizing a hyperbolic trajectory that intersects the parking orbit perpendicularly compared to one that intersects the parking orbit tangentially is enormous; his 20% figure can be true, but that is because he is comparing a bad solution to the correct one. This is not a 20% reduction compared to a well known and established trajectory. His claim that his overall solution is 20% more efficient than the well known and traditional trajectories is both incorrect and misleading.

Comparison of Results:

Mr. Clark provides the output of one of his solutions. It is a 5 impulse solution with the following results:

Delta-V 1	= 0.0956	km/s
Delta-V 2	= 3.5320	km/s
Delta-V 3	= 1.0000	km/s
Delta-V 4	= 1.7140	km/s
Delta-V 5	= 0.2416	km/s

Total: = 6.5832 km/s

A two maneuver solution between a low Earth orbit and a low Mars orbit has been generated using the same data and force model that Mr. Clark assumes. For reference, the following constants are used:

Semi-Major Axis of Earth's orbit about the Sun:	149599600.00	km
Semi-Major Axis of Mar's orbit about the Sun:	227943872.00	km

(Both orbits are assumed to be circular to be consistent with Mr. Clark's model)

Gravitational Parameter for the Sun:	1.32715D+11	km ³ /s ²
Gravitational Parameter for the Earth:	3.986D+5	km ³ /s ²
Gravitational Parameter for the Mars:	4.2828D+4	km ³ /s ²

Equatorial Radius of the Earth:	6378.137	km
Equatorial Radius of Mars:	3394.200	km

Altitude of Low Earth Parking Orbit:	200.0	km
Altitude of Low Mars Parking Orbit:	100.0	km

A two impulse solution connecting the low the Earth orbit with the low Mars orbit has been optimized using a standard nonlinear parameter optimization algorithm. The location of the initial impulse on the low Earth orbit, the time between the two maneuvers, and the location of the final maneuver on the low Mars orbit were chosen to be the free parameters. The cost of the optimization problem was the total velocity change magnitude. The result of the two impulse solution is:

Delta-V1	= 3.608	km/s
Delta-V2	= 2.114	km/s

Total	= 5.722	km/s
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This result could also have been found using optimal control theory (primer vector theory) which also determines whether more maneuvers are needed to reduce the cost. Additionally, a simple patched conic analysis between the low Earth orbit and the low Mars orbit yields a total Delta-V cost of 5.725 km/s. This last result is slightly higher than the full nonlinear optimization result because it does not take advantage of the mutual acceleration due to the Sun, Earth and Mars. The simple patched conic analysis is a technique taught in the first undergraduate course in orbital mechanics (ASE 366K Spacecraft Dynamics) and should be used as a nominal result against which all similar problems can be compared. Either way, the full nonlinear optimization result or the patched conic result both yield a solution that is 13% lower in Delta-V cost than Mr. Clark's solution; this is contrary to his claim.

Mr. Clark's solution is not optimal; though he may claim that his solution arrives 1 month earlier, this is no major revelation. It is known that any trajectory can be modified to hit the target earlier at the cost of fuel.

Further, in his documentation there are two instances where his numbers are inconsistent. At one point he states the savings is 20%; in another he cites that it is 25% more efficient. He never justifies his claim by comparing his solution to the well known solutions. If he did, he would realize that his solution requires more delta-v than the well known solutions.

The issue here is not the method that Mr. Clark's uses in his program, though it seems to be ad-hoc and unconventional. The issue is the fact that it provides an incorrect result and is not useful for real mission work because of the limiting assumptions he is using. The problem solved here is not a difficult problem to solve. Contrary to what Mr. Clark states, the use of a genetic algorithm is not required to solve this problem. Fundamentally, the problem, if it is well posed, can be solved with a simple differential correcting algorithm to get a feasible solution, and any standard optimization algorithm to obtain a locally optimal solution. Since the problem is simple, an initial guess for the parameters can be obtained from a short analytical calculation from fundamental orbital mechanics.

Again, had Mr. Clark provided a new solution and a new method that is better than all of the well known solutions and methods, then this would be an important result that would have

deserved our attention, regardless of whether it was unconventional. As a specialist in this area, I welcome such a result, provided it stands up against detailed scrutiny and verification. However, Mr. Clark has not provided this, and therefore, this work is not valid nor useful to the field.

His documentation is full of ambiguous and disconnected statements. This reviewer has concentrated on those aspects associated with his Earth to Mars trajectory analysis.



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March 19, 2002

Mr. William Clark, P.E.
21203 Paseo de Vaca Street
Lago Vista, TX 78645

Dear Mr. Clark:

In compliance with the official process established to address your formal grievance concerning dismissal from the Aerospace Engineering graduate program, an ad hoc panel consisting of members of the Graduate Studies Committee was convened. You have been notified about this panel in an email from Dr. David Hull on February 1, 2002. This letter contains the findings of the ad hoc panel, which was appointed to review your grievance. The panel, which I chaired, did not include Dr. Hull. By your choice, you removed Dr. Wallace Fowler from the panel. We have reviewed your undated appeal letter to Vice President Teresa Sullivan line by line, which was received on January 10, 2002. We address only those items in your letter that are relevant to your dismissal from the graduate program.

The ad hoc panel has confirmed that the Chair and Graduate Advisor had your research evaluated in December. You were advised of this review, but you chose not to keep an appointment with them to learn their findings. These findings and further elaborations are enclosed with this letter. In summary, based on a review of the materials that you officially submitted and signed on November 15, 2001, known as "Mars Pathfinder":

1) your materials exhibit serious misunderstandings of the foundations of celestial mechanics/orbital mechanics. Such misunderstandings are incompatible with the expectations of the faculty for a Ph.D. aspirant. A detailed discussion of these misunderstandings extracted from your materials is provided as Enclosure 1. Your claim to have shown "that Newton's Law of Equal Areas developed in the Principia (and Kepler's 2nd Law) is not valid, as it is supposed to be, for elliptical orbits" is unfounded. On the contrary, your own discussion is flawed and you have not shown, as you assert, that Newton's analysis was incorrect nor have you provided scholarly references to the literature where your assertions may be supported.

2) your materials lack the most fundamental aspect of scholarly research, viz., a literature survey. In fact, there are no significant references to related works in the published literature and how they relate to your study.

3) your assertions of optimality for the Earth-Mars trajectory contained in your materials are unfounded. In Enclosure 2, a review of your analysis is provided. It is shown in this review that standard methods of trajectory optimization provide even more efficient transfers than what you have found.

4) placement of your materials on an internet web site does not constitute scholarly publication of the materials. In fact, web site materials come and go, but scholarly materials published under the universally accepted peer review process will be available indefinitely through a reputable, archival journal or on a web site maintained and sponsored by a scientific organization.

The materials you submitted for review, known as "Mars Pathfinder", could not be considered for any scholarly report. The orbital mechanics faculty rejects this material as a draft thesis, draft dissertation or as a proposal for research in orbital mechanics. You suggest that the work is valid because you gave a formal seminar in November 2000 to students and faculty in Aerospace Engineering. However, it is an incorrect conclusion that presentation of a seminar is an endorsement of the technical content contained within the presentation. As an open University, we encourage the presentation of new ideas and new results. But *any* presentation is subject to open discussion and debate. In the final analysis, the ideas will be rejected if they do not withstand a rigorous scrutiny. In some cases, the faculty are reticent to openly challenge a student if they feel it will subject the student to embarrassment in the presence of peers. Such was the case in your November 2000 seminar.

To say that you have "never, ever gotten any feedback on my research from my advisor(s) or anybody else in the Department" is, for the most part, the result of your own decisions. After the November, 2000, seminar, Dr. Ocampo asked you to come by his office to discuss the material you presented and your research. You did not do so. Other requests by faculty members to discuss your research were not fulfilled by you. To our knowledge, you have not made an appropriate request that a faculty member review your materials. In an email you sent to me, dated July 3, 2001, you stated: "I'm Dr. Broucke's student - I've been working on an optimization of the Earth to Mars trajectory. I gave a presentation at the Department last fall. I've done a lot more work on the project, if you might be interested... You can download the program from my website at www.inviticus.com". I did not regard this email as a request that I review your material for its research potential. I did have a brief look at the material on your website, but in my cursory examination, I was left with the impression that the topics were disjoint, with nothing to link them together. In any case, the email stating "if you might be interested" was not an appropriate request for a formal review. The usual process is to make an appointment, provide the material beforehand and be ready to verbally discuss and/or defend the material at the appointment.

Your letter to Vice President Sullivan states that you "have a formal paper on this research project accepted as [sic] several conferences: and have a list of a dozen experts around the world whom [sic] have reviewed my work and are interested in it." These claims cannot be verified since you have not submitted the formal paper, where it was published, or the list of experts with your materials. In any case, presentation of a paper at a conference does not necessarily provide an indication of quality of research, unless the paper goes through an extensive peer review process. Since you have chosen to provide no information about the conferences, we can only state that in our judgement, a peer review process would not accept the papers for presentation at the conference. As in the case of the department seminar, many professional societies have an open forum policy where they accept most papers submitted for presentation. They have far *more rigorous policies* regarding peer review of papers for publication in their journals. Since you have provided no

information to this panel, we assume that none of your work has undergone such a peer review for publication.

With the preceding considerations, I spoke to each faculty member in the orbital mechanics area to determine if anyone would be willing to 1) serve as your Ph.D. supervisor or 2) to serve on your Ph.D. dissertation committee. No faculty members are willing to serve in either capacity and such agreement is an essential component of graduate work. You have not taken the research seriously by conducting a thorough literature survey in the area you have selected for research. Furthermore, you have refused to take advantage of opportunities to work with faculty members on a research problem and benefit from their experience and guidance in pursuing serious, scholarly research.

It is an established doctrine of the scientific method that the more extraordinary the claims that are made in an argument, the more substantial and incontrovertible the evidence must be to back these claims before they can be accepted. Not only do you present erroneous claims in your research materials, you do not treat the subject with seriousness or respect by presenting the necessary evidence required to substantiate your claims. In this regard, you do not show the most fundamental understanding of the scientific method which would be expected of a responsible researcher. Your research claims are at best frivolous and without substance. At their worst, they are irresponsible and orthogonal to academic standards for research.

As a consequence of the foregoing considerations, the panel finds no merit in your grievance. The panel supports the dismissal decision relayed to you in the letter of December 14, 2001, from Professors Hull and Dolling.

The panel wishes you well and much success in your future pursuits.

Sincerely yours,



B. E. Schutz, P.E. 46786, State of Texas
Joe. J. King Chair in Engineering and
FSX Professor of Space Applications and Exploration
Ad Hoc Review Panel Chair

Enclosures

cc:

Ad Hoc Review Panel
Dr. David Dolling
Dr. David G. Hull
ASE Graduate Studies Committee