Hughes Helicopters, Inc.

Computer Aided Engineering and Finite Element Applications to Weapon Systems

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ABSTRACT

Finite Element methods and animated computer graphics were applied in the analyses of Hughes Helicopter 25mm and 30mm gun systems.

In a joint project Hughes Helicopters, Inc. and SDRC, Inc. explored the application of CAE to the design of a weapon station for an Armored Fighting Vehicle (AFV). System dynamic analysis using component modal data for the 25mm gun and armored fighting vehicle was performed with aids of MSC NASTRAN and SDRC software with animated color graphic packages. During the course of the analysis a communication link was set up for transmitting converted NASTRAN output data between a CDC mainframe and VAX mini computer. The analysis procedure was documented on video tape.

In a second analysis, the transient reponse of the 30mm gun was performed by employing some of the non-linear load features in MSC NASTRAN. A fortran program was written to combine and convert NASTRAN linear and non-linear load outputs into plot format from which force time histories could be created. Parametric studies for optimizing the gun energy absorption system can be accomplished without involving extensive testing.

INTRODUCTION

During the last year, Hughes Helicopter, Inc. (HHI) directed a concerted effort towards developing analytical techniques to assist in the design, evaluation, and application of ordnance systems and components.

One significant research project resulted in the documentation, on a video cassette, of the application of Computer Aided Engineering (CAE) and Finite Element Element Methods (FEM) for design and system analysis of a 25mm M242/Armored Fighting Vehicle Weapon Station.

An important objective was to evaluate the efficiencies gained through the use of interactive color graphics and an integrated data base as the development proceeded from component conceptual design through total system structural dynamic analysis. Emphasis was placed on the use of interactive color graphics to improve communication and decrease product development time and cost.

Another accomplishment in 1983 was the modeling and transient response analysis of the 30mm Chain Gun performed by employing some new "nonlinear" load features in the MSC/NASTRAN Finite Element Program. Parametric studies for optimizing the gun energy absorption system were accomplished without involving extensive testing.

APPLICATION

The analysis of the 25mm M242 gun system represented a joint project with Structural Dynamics Research Corporation (SDRC). SDRC had recent experience in the Finite Element Modeling of Armored Fighting Vehicles (AFV), and also had a new release of their CAE software package which we were anxious to review. The software, the "I-DEAS" package, included 3-D solid modeling with color animated graphic displays and modal synthesis capabilities compatible with NASTRAN.

The model of the Hughes 25mm gun was developed and analyzed using MSC/NASTRAN on a Control Data Corp. mainframe located in the remote computing facilities of the McDonnell Douglas Automation Co. (MacAuto), St. Louis. After logging on the system, and working on the model, Hughes engineers used telecommunications to transfer the results to the SDRC system database supported by a Digital Equipment Corp. "VAX" mini computer. One of the major accomplishments was the SDRC conversion of NASTRAN binary coded output data to character set data for use on a smaller "bit" computer.

The model of the gun represents only one component of the project. SDRC was also responsible for the design and analysis of the tank, wheel, turret, and engine. The ability for people in different locations to independently develop component models on different machines and synthesize them into a system model was an achievement.

Geometric solid modeling was used in the conceptual design stage and component models, such as the power pack, (Figure 1) were created. System level packaging, configuration, mass, and inertia studies were performed by assembling these component models into a system solid representation shown in Figure 2. The motion of the turret and gun was animated using a kinematic analysis module; any interference was calculated automatically and displayed as interference volumes.

The building-block approach was used to study the structural dynamics of the complete system. Components such as the power pack and turret were represented as rigid bodies and the appropriate properties were automatically available in the common data base from the geometric solid model. No further calculations or transfer of data were required.

The gun and hull were represented by their respective modal characteristics as determined from dynamic finite-element analyses. Figure 3 shows the NASTRAN 906 element model of the 25mm gun. Seventeen component modes were calculated using solution 3. Data blocks necessary for the system analysis were

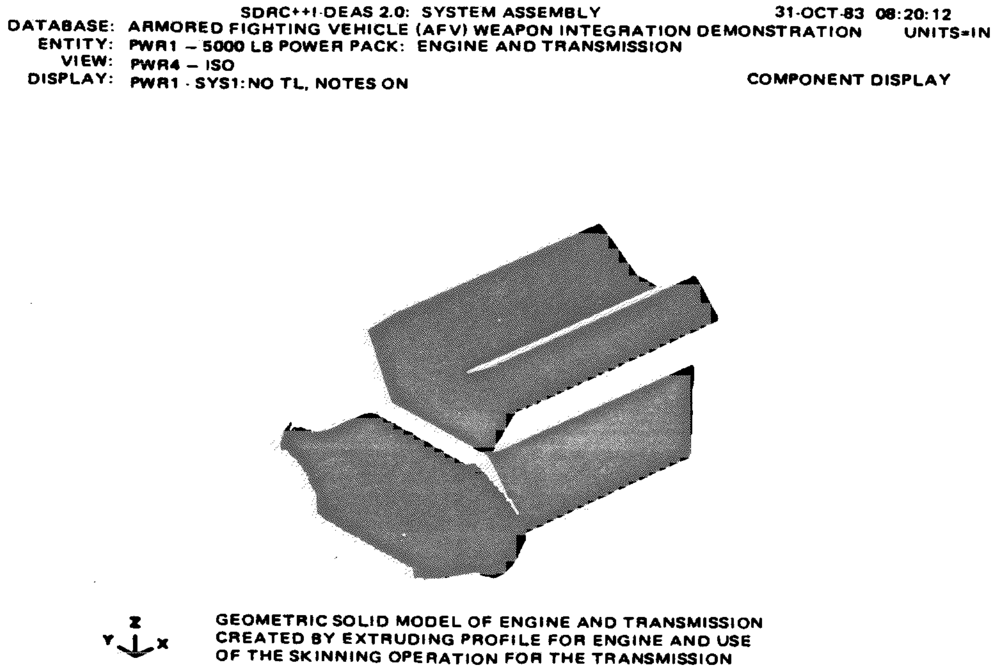


Figure 1. Geometric Solid Modeling

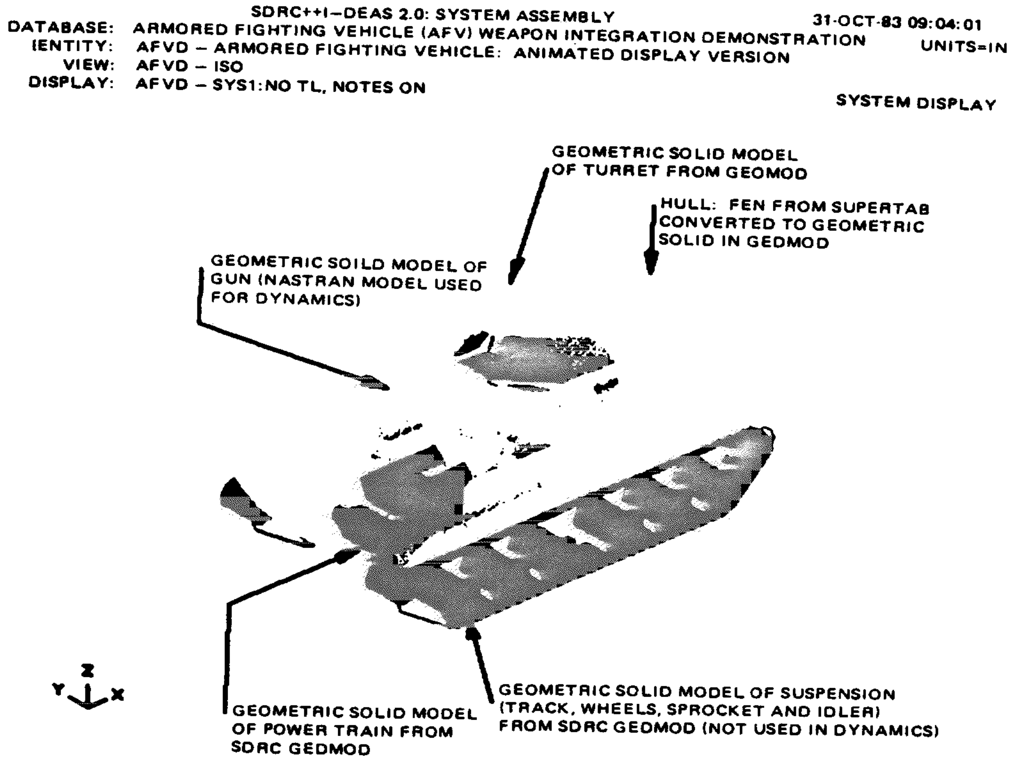


Figure 2. System Level Modeling

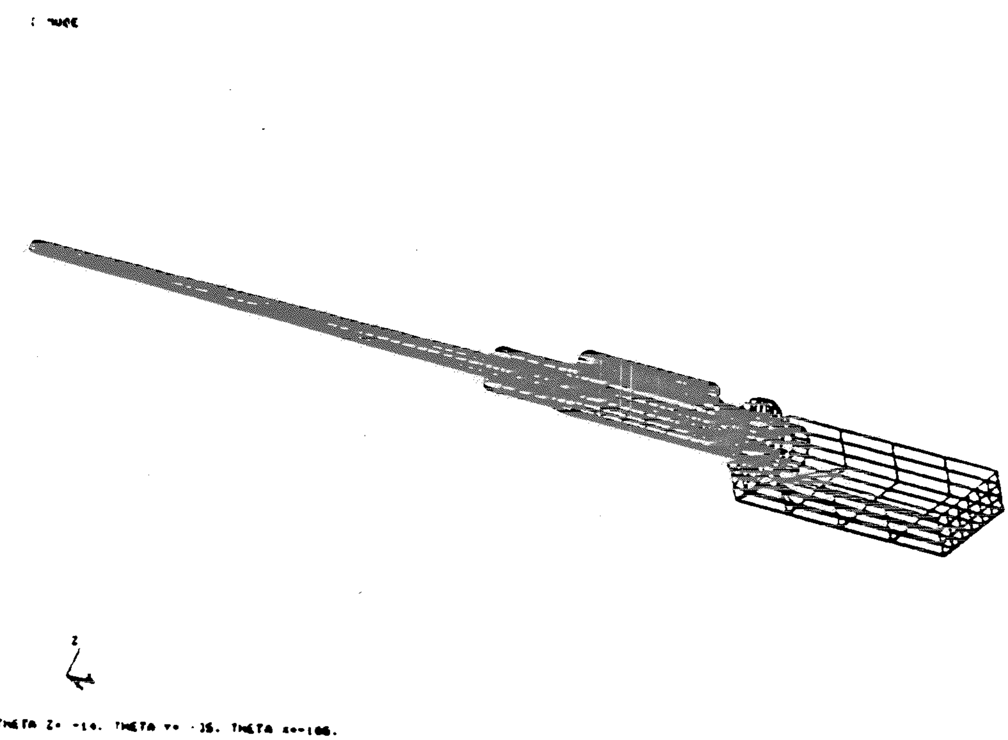


Figure 3. 25mm Gun Model

written to the output2 file. The hull model was developed within the Integrated system data base, sharing geometry with the geometric solid model. MSC NASTRAN was used to determine 33 free-free modes below 100 Hz. Again, the NASTRAN-determined modal parameters were read into the SDRC "SYSTAN" program automatically, for use in a system model of the AFV in order to study the structural dynamic aspects of weapon system integration. Hidden line, color shaded image, and "trace link" displays were used to evaluate component models prior to system analysis.

Thirty modes of the complete system were calculated. Animated displays of the modes were created, which in conjunction with the use of color provide a great deal of insight into complex system interactions. Coupled gun bending and power pack pitch (Figure 4) at 7 Hz are an example. Such system level interactions can cause significant problems and are often overlooked if a system dynamic analysis is not performed.

Several forced response analyses were performed using the system modal data base. The responses of the gun tip to traversing a rough terrain and to the gun firing pulse were calculated and used as a measure of gun accuracy. The contributions of the individual system and component modes were also calculated and used to assist the design engineer in understanding and eliminating the causes of any unacceptable behavior. A typical response plot showing the vertical gun tip power spectral density is shown in Figure 5.

Figure 4. Pitch Mode

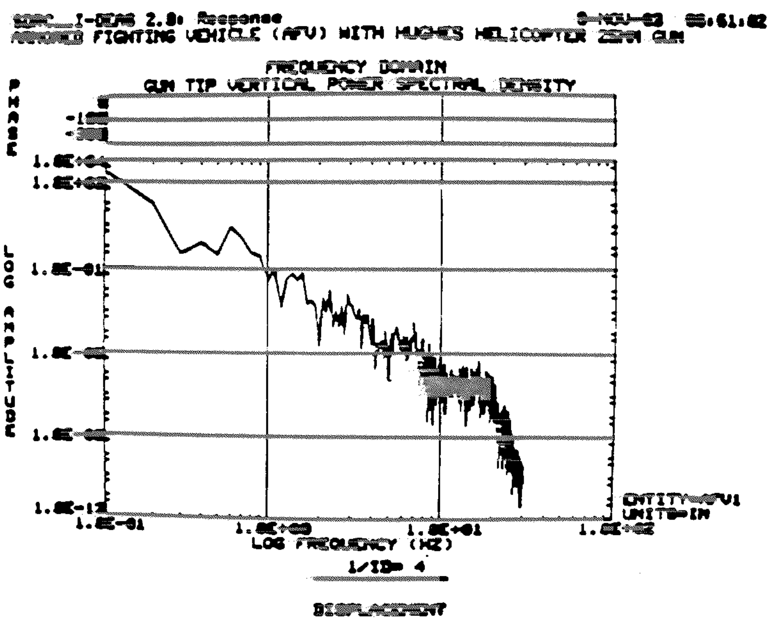


Figure 5. Typical Response Plot

As a result of the study it was concluded that CAE and Finite Element Methods were tools of significant benefit in such applications. Specifically, use of interactive color graphics greatly enhanced the display, understanding, and communications of both component and system level design concerns (e.g., packaging, configuration, and dynamics). Documenting the project on video tape provided a unique method for displaying the approach and results, as well as capturing the impact of color displays. The tape has been viewed by management and engineers within the Aerospace community and received favorable reviews both in demonstrating CAE and as a means of documenting and presenting results.

The entire project was completed within six weeks.

A separate study consisting of a nonlinear transient response analysis of the 30mm chain gun was performed. Figure 6 shows the AH-64A Apache Helicopter which includes the 30mm gun mounted under the nose section as part of its armament, in addition to a variety of missiles and rockets. Figure 7 and 8 show schematic representations of the gun/ship installation and descriptions of the components of the 30mm chain gun turret system respectively.

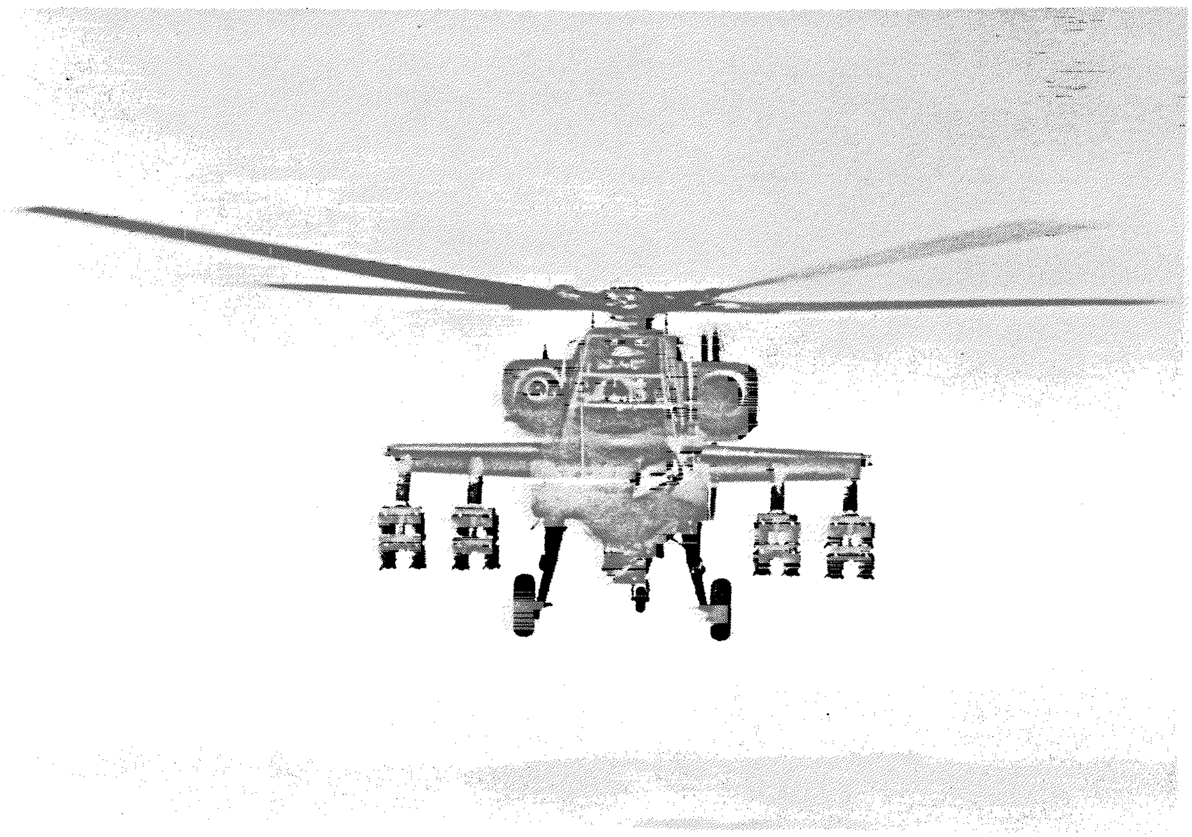


Figure 6. AH-64A Apache Helicopter

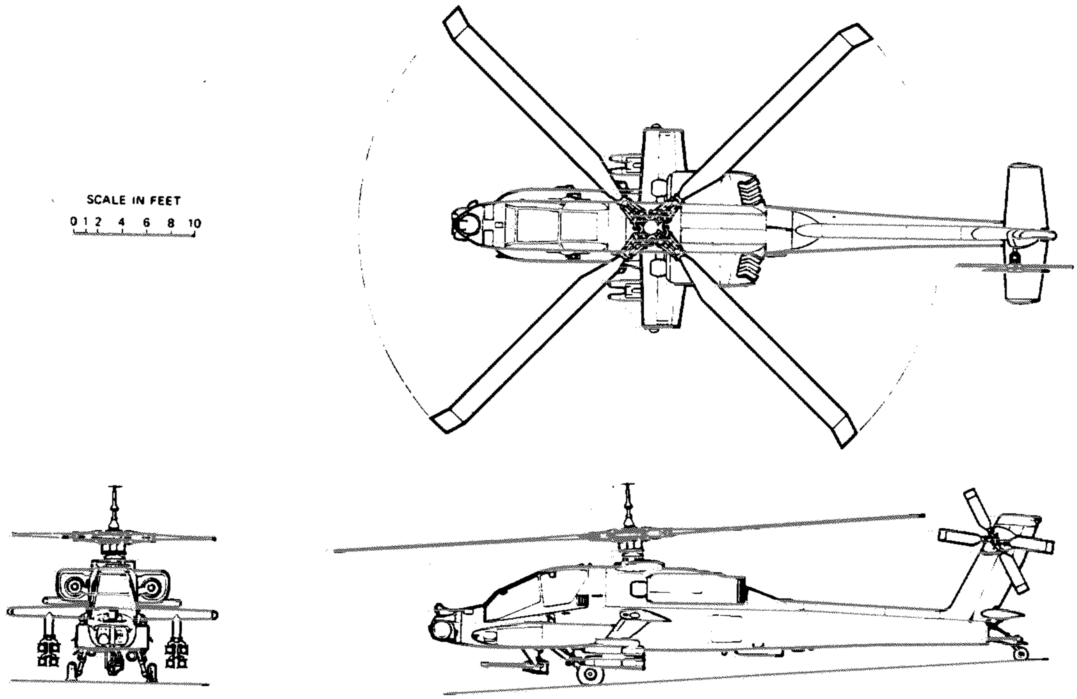


Figure 7. Views of the Apache

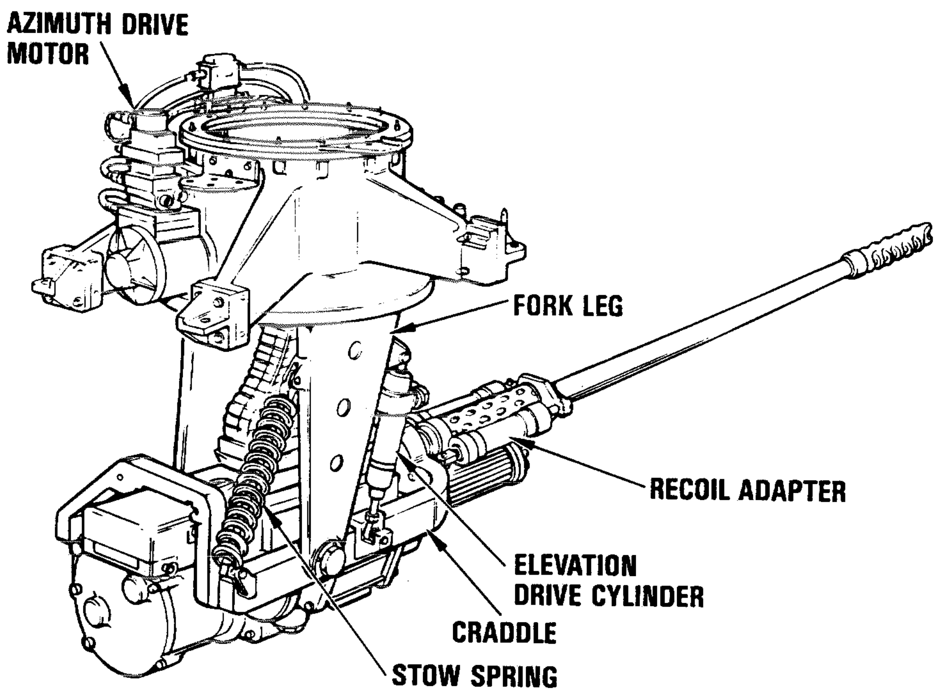


Figure 8. 30mm Chain Gun Turret System

A NASTRAN model consisting of 175 elements and 740 degrees of freedom was developed as illustrated in Figure 9. A limited amount of shake test data was available. Two of the calculated undamped modes (Figure 10 and 11) were used for correlation with the limited test data. The 30mm chain gun is a highly damped system, with the recoil adapters being the main contribution. The problem confronted by the analyst was that damping values of gun recoil adapters varied due to variable metering pin diameters as illustrated in Figures 12 and 13. The MSC/NASTRAN program has capabilities of capturing this phenomenon through the application of a series of nonlinear forces and transfer functions.

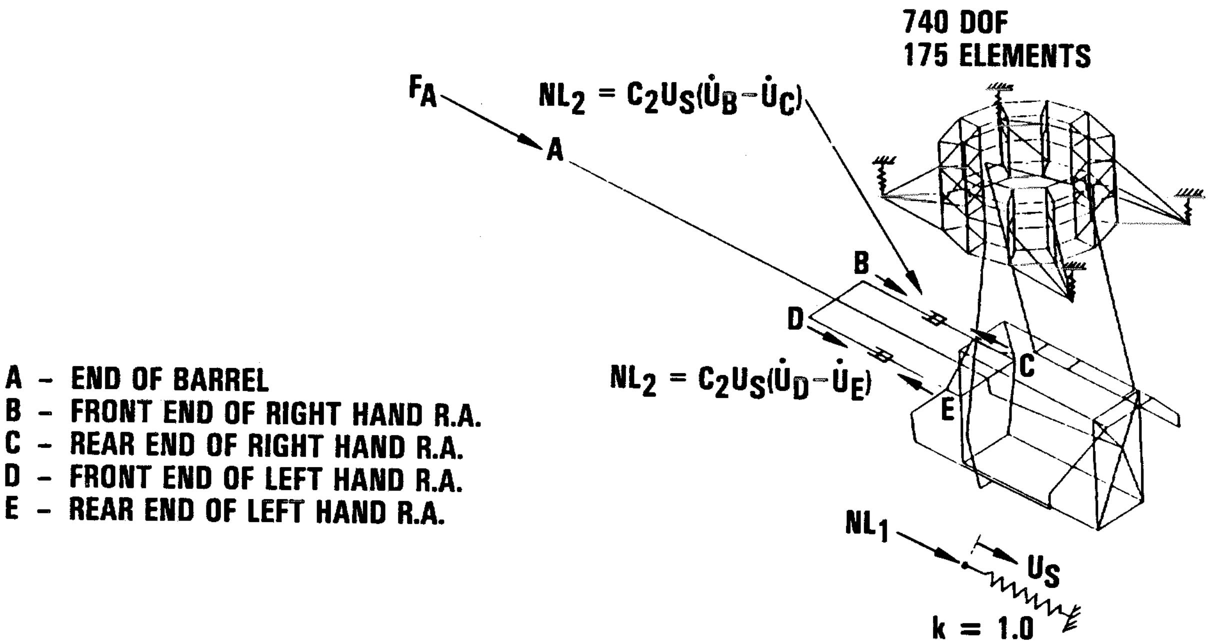


Figure 9. NASTRAN Model of 30mm Chain Gun Turret System

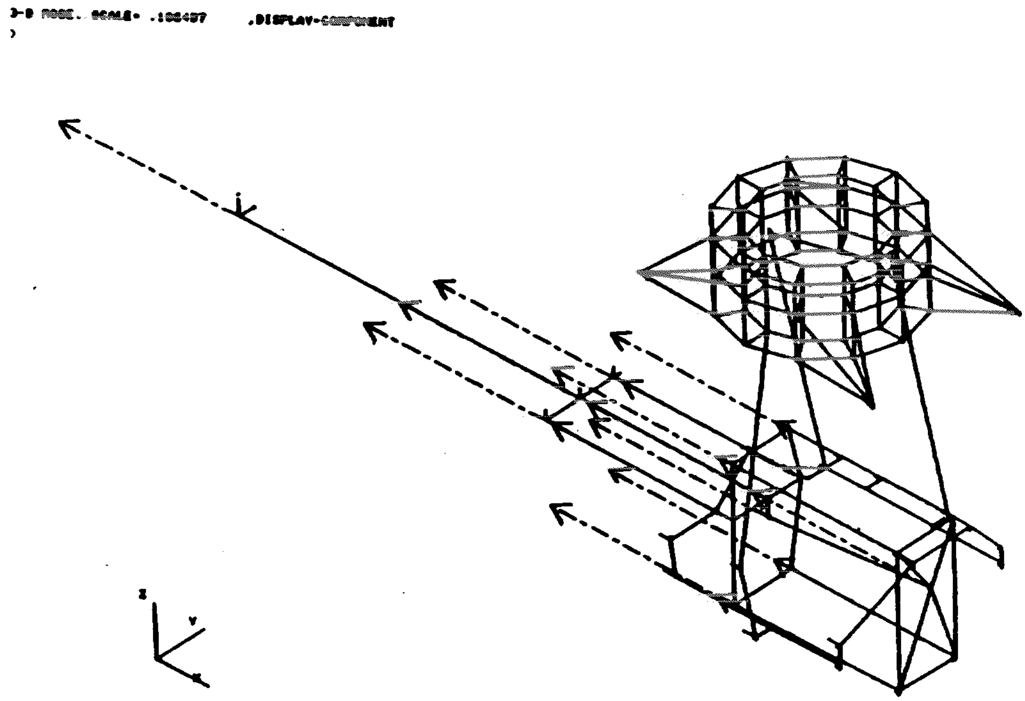


Figure 10. First Undamped Mode/Fwd-Aft Logitudinal Mode

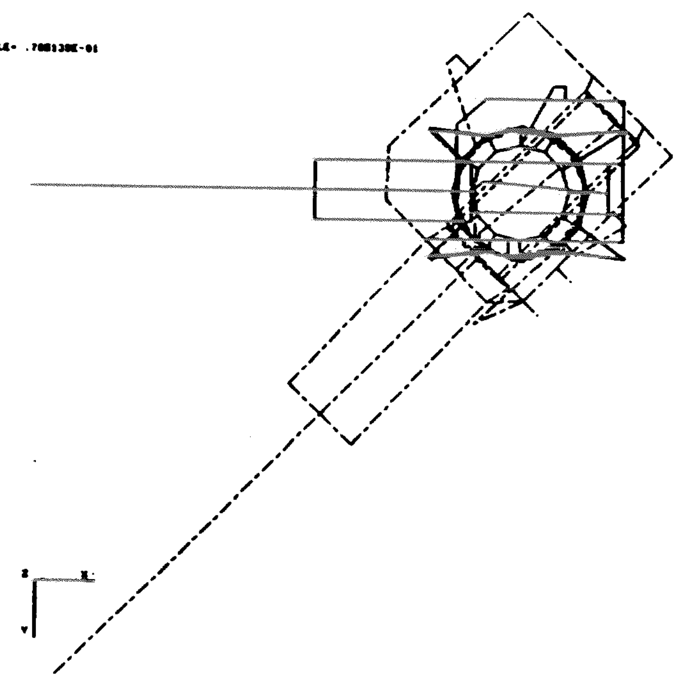


Figure 11. Second Undamped Mode/Azimuth Mode

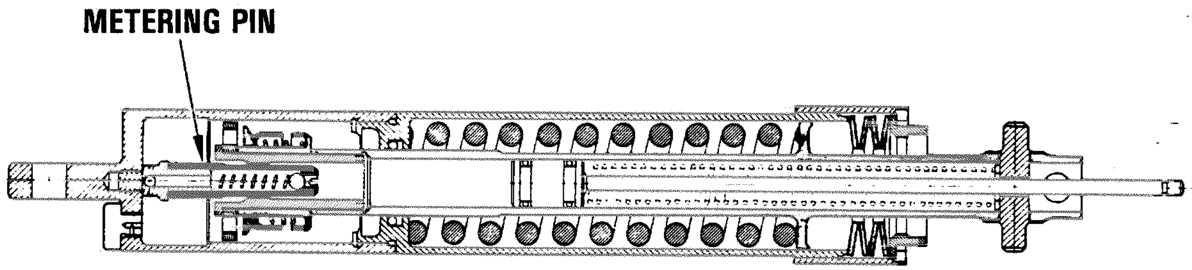
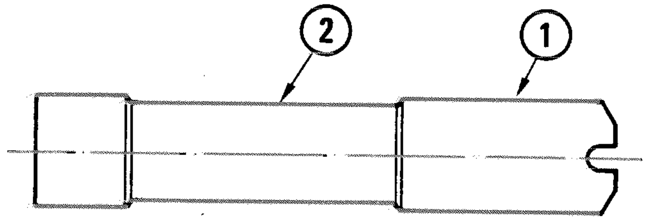


Figure 12. 30mm Chain Gun Recoil Adapter



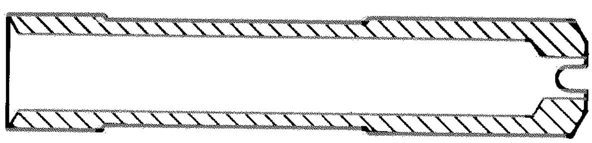


Figure 13. 30mm Chain Gun Recoil Adpater
Metering Pin

The recoil adapter loads were functions of both the velocity and displacement. The scheme was to model the initial portion of the recoil adapter as a constant linear damper. The change in damping value as the diameter of the metering pin changes could be accounted for, by adding (plus or minus) the difference in damping force. A "NOLIN1" card, which is comprised of "TABLED1" and "TF" (Transfer Function) data were used as a switch to monitor when the damping force was to be added. "NOLIN2" card defined the actual difference in damping force. Embedded in NOLIN2 were the difference in damping value, transfer function defining the relative velocities of the end points of the recoil adapter, and a coefficient obtained from NOLIN1 in determining the amount of increment or reduction in damping force from the linear portion. Figure 14 comprised a complete summary of the procedures for implementaiton of nonlinear forces in recoil adapters.

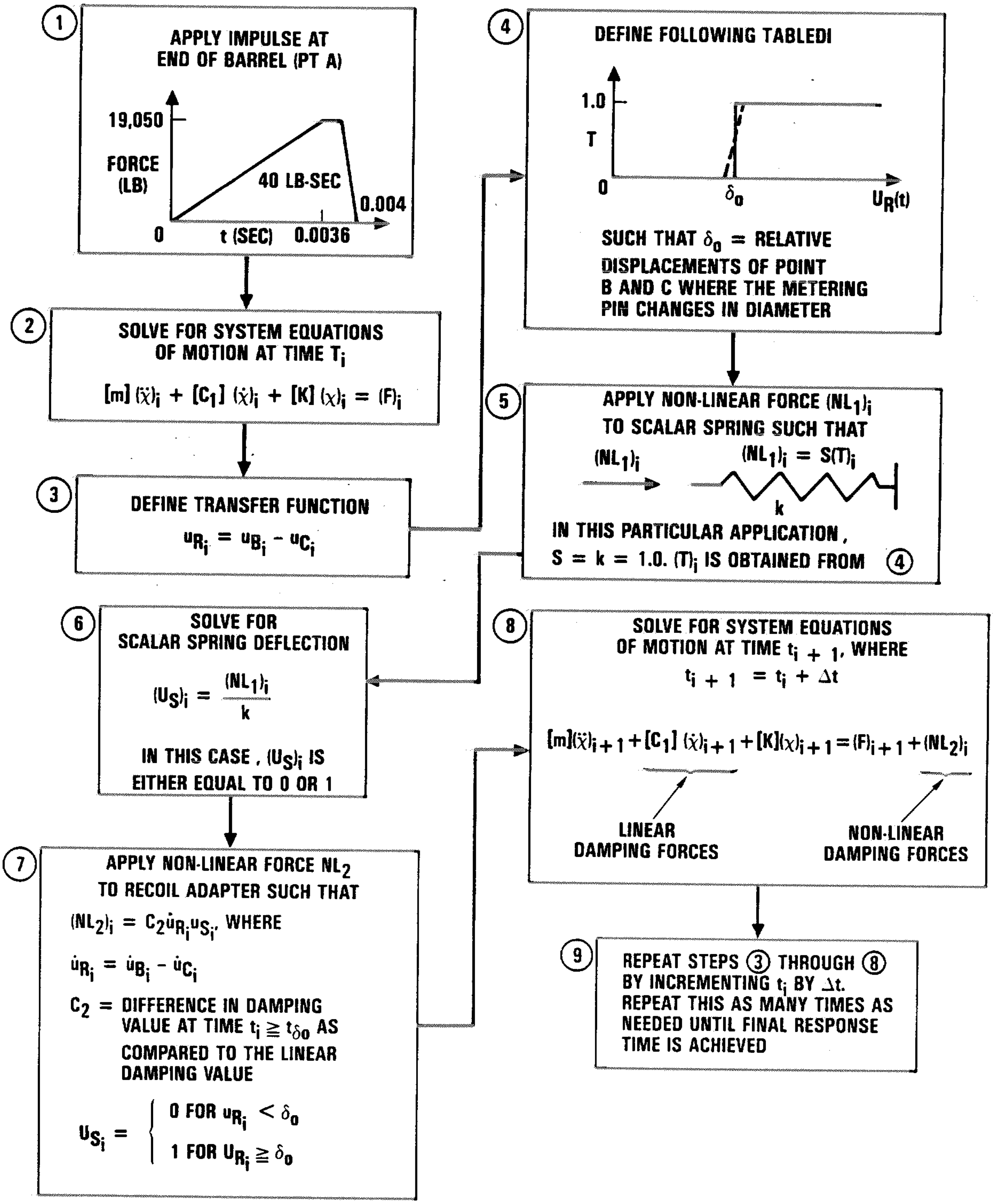


Figure 14. Procedures for Implementation of Nonlinear Forces in Recoil Adapter

A FORTRAN program was written to combine the linear damping force, nonlinear damping force and the spring force to yield the total recoil adapter force. Current MSC NASTRAN XYPLOT features do not have the capability to plot the combined loads. Although one could bypass this shortcoming by adding a very stiff spring in series and plot the spring load itself. However, aside from just plotting load time history, we were also interested in cross plotting load versus relative displacement. Furthermore, for this particular application, the turret-fuselage interface bolt loads were also calculated. All these features along with conversions to plot format were included in the FORTRAN program. A summary of how the NASTRAN outputs were combined and converted to plot files were illustrated in Figure 15. Figures 16 and 17 featured typical outputs from the FORTRAN conversion program.

As a further application, optimization of the metering pin could be accomplished by using the nonlinear load features. Theoretically, the metering pin could have 'N' number of steps. However, there would be a tradeoff in feasibility of manufacturing and cost effectivensss.

For a multiple steped metering pin, analytical procedure could be implemented similar to the two stepped pin. The only variation would be in the TABLED1 card as shown in Figure 18.

As an example, a four stepped metering pin (Figure 19) was analyzed and compared with the results from the baseline two stepped pin. Clearly, as indicated in Figures 20 and 21, the four step metering pin was more efficient as an energy absorber, while producing lower loads for the same deflection.

The damping force in reality is a function of the displacement and velocity squared ($F_d = a_1 a_2(dist_i)\dot{X}^2$). The displacement dependent term $a_2(dist_1)$ is a result of a non-uniform metering pin diameter and would be a constant provided the diameter was uniform. For a linear approximation, as in a viscous damper, we equate $C_i = a_1 a_2(dist_i)\dot{X}$. Since we had some actual gun firing recoil adapter load time histories for the baseline (two step metering pin case), we varied C_1 and C_2 until our analytical curve fell within an acceptance range of test curves (Figure 22). The sets of C_1 and C_2 would be valid for this particular turret system configuration. From there, we performed sensitivity studies by varying C_i and the distances where C_i changed to arrive at a more optimum design.

For future studies, we will investigate the implementation of a control servo system and the inclusion of the velocity squared term without using linear approximations in arriving at the viscous damping values.

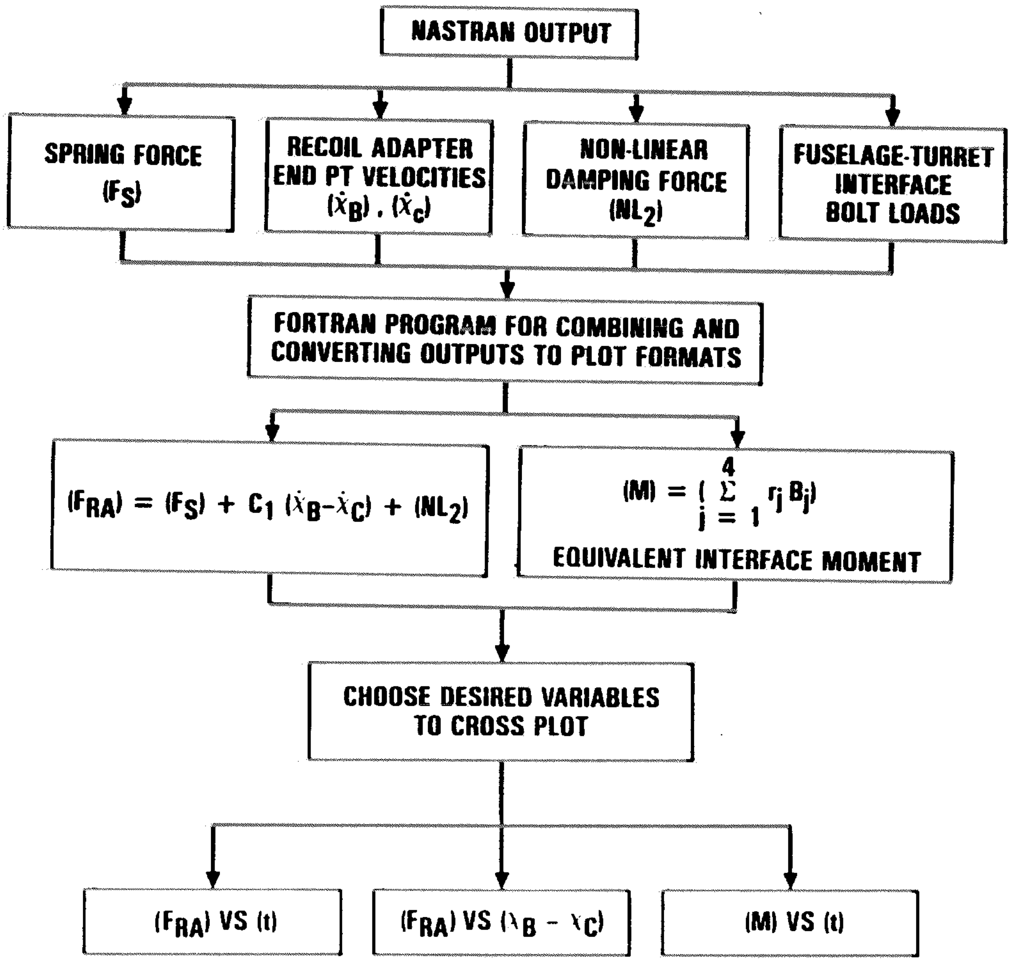


Figure 15. FORTRAN Program for Conversion of NASTRAN Output for Better Interpretation of Results

*** 30 MM GUN RECOIL ADAPTER ENERGY ABSORPTION CHARACTERISTICS ***

		RIGHT R.A.	LEFT R.A.
MAX RECOIL LOAD	=	919.	923.
MAX RECOIL STROKE	=	1.	1.
100 PERCENT OF ENERGY	=	942.	945.
MAXIMUM ENERGY	=	821.	818.
EFFICIENCY	=	.871	.866

*** TURRET-FUSELAGE INTERFACE MOMENT ***

MEAN MOMENT (IN-LB)	=	22551.
CYCLIC MOMENT (IN-LB)	=	31793.

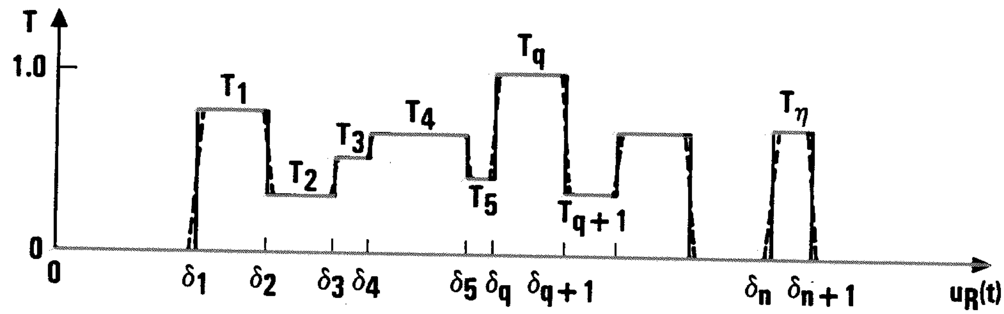
Figure 16. Summary of Results of Interest

*** RECOIL ADAPTER LOAD-DEFLECTION CHARACTERISTICS ***

TIME (SEC)	RIGHT R.A. LOAD(LB)	RIGHT R.A. DEF(IN)	RIGHT R.A. EG (IN-LB)	LEFT R.A. LOAD(LB)	LEFT R.A. DEF(IN)	LEFT R.A. EG(IN-LB)	TOT RECOIL LOAD (LB)	INT MOMENT (IN-LB)
0.	0.	0.0000	0.	0.	0.0000	0.	0.	0.
.500E-03	28.	.0003	0.	26.	.0003	0.	54.	2.
.100E-02	106.	.0021	0.	102.	.0020	0.	208.	65.
.150E-02	227.	.0066	1.	221.	.0064	1.	447.	371.
.200E-02	385.	.0146	3.	379.	.0143	3.	764.	1196.
.250E 02	573.	.0268	9.	570.	.0262	9.	1143.	2879.
300E-02	656.	.0438	20.	656.	.0432	19.	1312.	5701.
.350E-02	879.	.0670	37.	874.	.0662	37.	1753.	9778.
.400E-02	832.	.0967	63.	845.	.0958	62.	1677.	15312.
.450E-02	742.	.1265	86.	742.	.1258	86.	1484.	21989.
.500E-02	737.	.1546	107.	726.	.1537	107.	1463.	28773.
.550E-02	755.	.1825	128.	732.	.1810	126.	1487.	35375.
.600E-02	796.	.2113	150.	766.	.2087	147.	1562.	41314.
.650E-02	849.	.2414	175.	827.	.2378	170	1676.	46316.
.700E-02	900	2732	203.	879	.2687	197.	1778.	50218.
.750E-02	866.	.3067	232.	914.	.3015	226.	1780.	52961.
.800E-02	744.	.3424	261.	755.	.3370	256.	1499.	54344.
.850E-02	805.	.3811	291.	804.	.3759	286.	1609.	54121.
.900E-02	855.	.4223	325.	844.	.4171	320.	1699.	52539.
.950E-02	887.	.4648	362.	903.	.4599	357.	1790.	49923.
.100E-01	904.	.5077	401.	906.	.5032	397.	1810.	46611.
.105E-01	909.	.5502	439.	902.	.5460	435.	1811.	42938.
.110E-01	903.	.5914	477.	923.	.5877	473.	1826.	39175.
.115E-01	884.	.6308	512.	882.	.6274	509.	1766.	35594.
.120E-01	859.	.6678	544.	849.	.6646	541.	1707.	32381.
.125E-01	831.	.7021	573.	849.	.6991	571.	1681.	29675.
.130E-01	795.	.7335	598.	788.	.7306	596.	1583.	27567.
.135E-01	759.	.7620	621.	747.	.7591	618.	1507.	26090.
.140E-01	732.	.7876	640.	749.	.7847	637.	1481.	25221.
.145E-01	880.	.8106	658.	817.	.8077	655.	1697.	24905.
.150E-01	919.	.8303	676.	897.	.8271	672.	1816.	25383.
.155E-01	830.	.8462	690.	853.	.8429	686.	1683.	26729.
.160E-01	770.	.8595	700.	765.	.8565	697.	1534.	28572.
.165E-01	734.	.8713	709.	729.	.8685	706.	1463.	30581.
.170E-01	733.	.8824	717.	754.	.8796	714.	1487.	32495.
.175E-01	734.	.8932	725.	722.	.8905	722.	1456.	34132.
.180E-01	740.	.9042	734.	728.	.9014	730.	1467.	35375.
.185E-01	762.	.9154	742.	780.	.9126	738.	1541.	36166.
190E-01	771.	.9268	751.	756.	.9240	747.	1526.	36498.
195E-01	772.	.9384	760.	759.	.9355	756.	1531.	36402.
200E-01	781	9500	769.	802.	.9470	765.	1583.	35936.
205E-01	772	.9613	777.	760.	.9584	774.	1532.	35177.
210E-01	752	9721	786.	744.	.9693	782.	1495.	34211.
215E-01	740	9823	793.	765.	.9795	790.	1505.	33124.
220E-01	710	9915	800.	701.	.9889	797.	1410.	31998.

Figure 17. Summary of Results of Interest

MULTIPLE STEP CHANGE CAN BE INCORPORATED SIMPLY BY REPLACING STEP ④ WITH THE FOLLOWING TABLEDI



T_i DOES NOT NECESSARILY HAVE TO BE A MONOTONIC FUNCTION. FOR CONVENIENCE, SET $T_q = 1.0$ AND $C_2 = C_q$ IN STEP ⑦ AS THE MAXIMUM DIFFERENCE IN DAMPING VALUE AS COMPARED TO C_1

Figure 18. Multiple-Steps Metering Pin

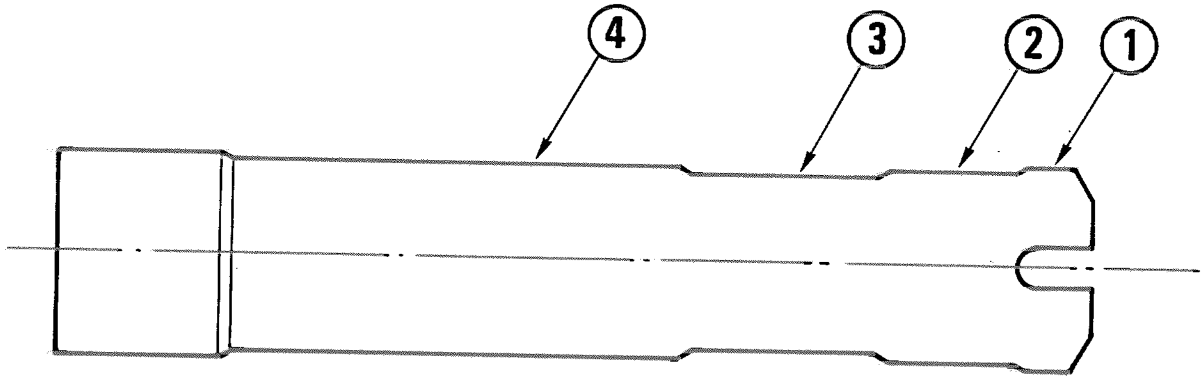


Figure 19. Four-Steps Metering Pin

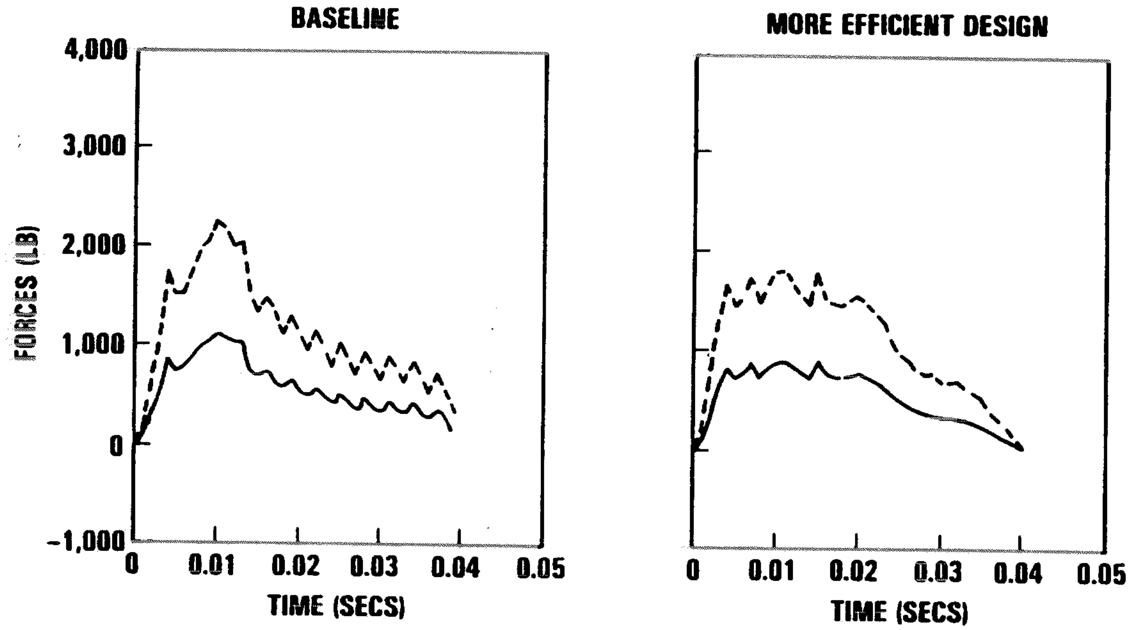


Figure 20. Force-Time Histories of Metering Pin

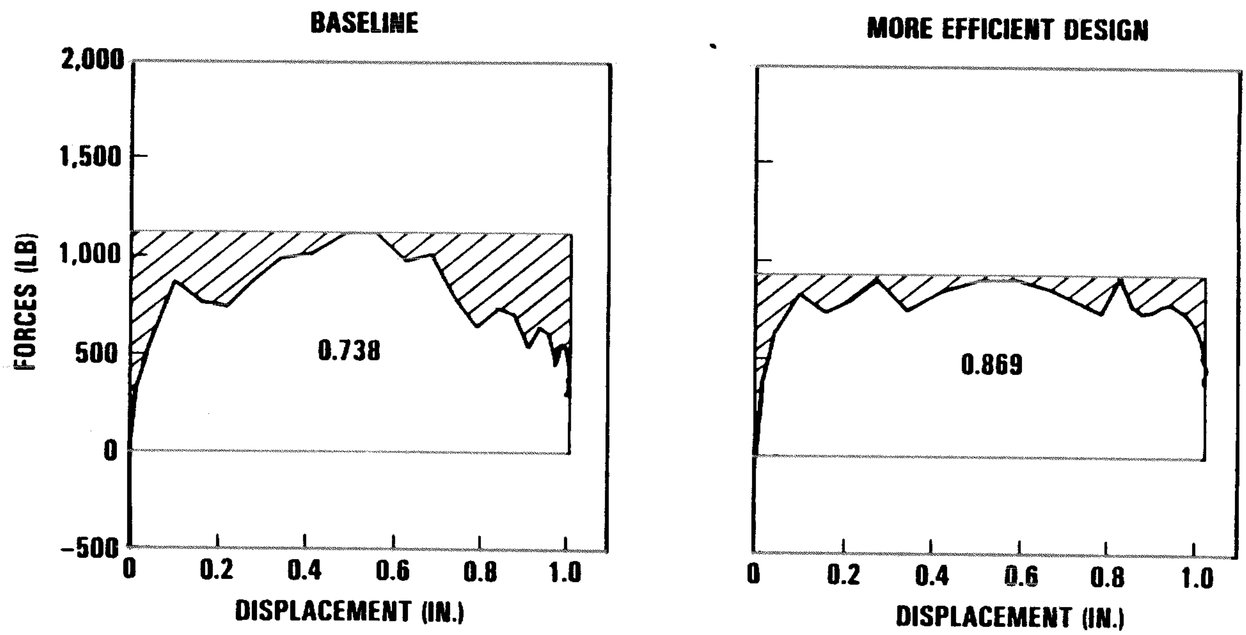


Figure 21. Load-Deflection Curves of Metering Pin

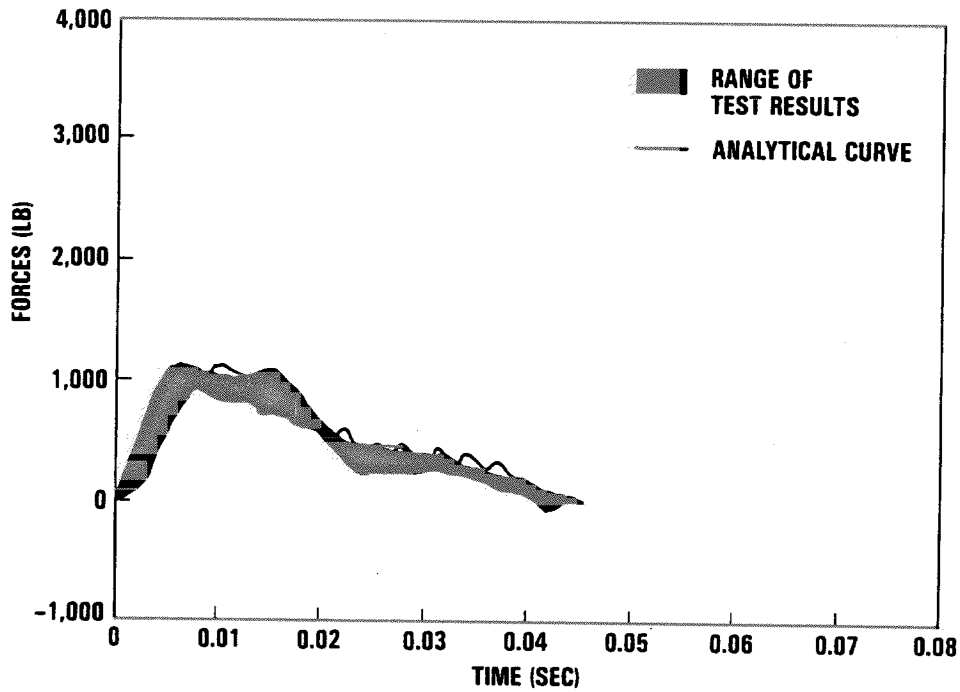


Figure 22. Comparison of Analytical and Test Results

ACKNOWLEDGEMENT

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