AADE 01-NC-HO-34

Drilling Efficiencies Provided by Hydraulic Thrusting Devices

Corles A. Giles, BP, Tony Seesahai, BP, John W. Brooks, Smith International Inc., Wilmark Johnatty, Trinpet

Copyright 2001 AADE National Drilling Technical Conference

This paper was prepared for presentation at the AADE 2001 National Drilling Conference, “Drilling Technology- The Next 100 years”, held at the Omni in Houston, Texas, March 27 - 29, 2001. This conference was hosted by the Houston Chapter of the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individuals listed as author/s of this work.

Abstract

This paper reviews the benefits provided by the use of thrusting devices in medium to high angle and horizontal well bores, when used as part of a steerable drilling assembly. Results of evaluations are based on performance as related to penetration rate and down hole tool failure rates that usually requires a round trip. In all, eighty-five (85) bottom hole assembly (BHA) runs on three aggressive development projects for BP-Trinidad were studied. Over 162,000 feet were drilled with 3,500 tool circulating hours accumulated since the study began in November 1997. Data was sourced from drilling ASCII data, daily drilling reports, directional well reports, measurement-while-drilling (MWD) and mud logging final well reports. It was concluded that when BHAs included a properly placed thrusting device, significantly improved penetration rates can be expected.[1,2] This is especially the case when experiencing difficulties related to high hole angle problems. In using thrusting devices, a dramatic reduction in failure rates for down hole equipment was also seen, particularly with MWD and logging-while-drilling (LWD) equipment.

Introduction

Thrusting devices were first used in BP-Trinidad’s drilling operations with the start-up of the Mahogany A development in January 1998, offshore Trinidad. Subsequently, thrusting devices were used on the Immortelle Phase 4 development project offshore Trinidad. The use of thrusting devices became wide spread on these projects and continued to be used in the development of the Mahogany B project. Thrusting devices varying in design and manufacture were utilized on these projects.

Many of the drilling projects in the Mahogany and Immortelle fields since January 1998 consisted of high angle wells drilled from new slots in underdeveloped horizons, with some of them being horizontal wells. Most of these wells were completed in 12-¼” holes and sometimes 8-½” holes (laterals). Prior to the application of thrusting devices, much difficulty was experienced in meeting the objective of drilling the 12-¼” hole section to casing point in one PDC bit run using water based drilling fluid. Prior to use of thrusting devices, the 12-¼” hole objective had only been achieved once in the history of these projects. The normal well profile is for the 12-¼” hole section to start vertically at approximately 4,000 feet and kick-off between 4,000 to 6,000 feet. The hole angle is then built to 25 – 70 degrees and held tangentially, or built to 90 degrees for an 8-½” hole size horizontal well. The difficulties encountered included weight-stacking, stick slip, excessive down hole torque, frequent motor stalling and poor sliding performance.

Thrusting devices were considered initially for two primary reasons – to improve rate-of-penetration (ROP), and to reduce down hole tool failure (DTF). Drilling performance issues that were to be addressed by using thrusting devices included:

- Reduce weight-stacking problems that are associated with PDC bits run with positive-displacement-motors (PDMs) in high angle wells.
- Improve the ability to maintain tool face and increase penetration rates during sliding / orienting intervals.
- To reduce axial shock loads and reduce tool failures, particularly in the MWD/LWD equipment that have high cost and long turn around times.

Results of this study show that thrusting devices impact favorably on these and other drilling environments. This study has two primary areas of focus. The first has to do with the evaluation of drilling performance and penetration rates hereafter referred to as the ***ROP Study***, and the other having to do with the evaluation of down hole tool failures hereafter referred to as the ***DTF Study***.

Principles of Thrusting Devices

Established benefits of thrusting devices are for improving drilling performance by applying consistent weight-on-bit (WOB). Other benefits provided by these tools is to help in reducing the common problems and equipment damages associated with high shock loading often seen in high angle wells. In most cases, the tool should improve the rate of penetration, extend bit life and extend the life of other components run in the bottom hole assembly.

A thrusting device acts like a hydraulic piston pushing downwards when placed properly in the BHA. This axial force, both upwards and downwards, is created by the differential pressure losses of the bit nozzles and other bottom hole assembly components below the tool. The magnitude of the force produced by the tool is also a function of the fluid mandrel area (piston area) of the tool, since fundamentally:

$$\textit{Force (lbf) = Pressure (psi) x Area (in}^2\textit{)} \qquad (1)$$

The fluid mandrel piston area of the thrusting device discussed is variable depending on the tool size, from 5.6 in^2 to 44.2 in^2, and will accommodate a wide range of drilling (or milling) applications. The axial motion from the bit is isolated from the rest of the drill string, which prevents further build-up of axial vibrations. The result is a constant WOB, and reduction in the shock loading created by bit bounce. Tool face control, weight-stacking, and mud motor stalling problems normally associated with high angle wells will also be minimized with the use of a thrusting device.

Study Objective

The purpose of the study was to quantify what impact thrusting devices had on the drilling operations for three development platforms for BP in Trinidad. Thrusting devices were adopted to improve sliding in difficult mechanical conditions, and to help improve down hole tool (MWD, LWD, PDM and other BHA components) failure rates. After the first 12 months of using thrusting devices on two rigs involved, there was a need to document the results of using thrusting devices. This study was commissioned by BP-Trinidad (formerly Amoco Trinidad Oil Company) in December 1998, to determine the benefits of thrusting devices.

The study was done over a three-year period covering most of the wells drilled on three platforms. As previously mentioned, eighty-five BHAs (drilling 162,000 feet) were studied. It was determined that statistical errors and other anomalies that could skew conclusions would have minimal impact due to the extensive data population.

Data & Evaluation Methods

The data is from wells drilled offshore Trinidad by BP over the period from November 1997 to March 1999. These wells were all deviated wells ranging from 16 to 90 degrees. The well types varied from gas completions to horizontal completions into oil reservoirs. The evaluation is an ongoing exercise for development projects at BP-Trinidad (and has continued over to the more recent Amherstia development project).

General aspects of the data population are shown in Table 1. Note that the data population consisted of data collected from the12-¼" and 8-½" hole sections only.

Table 2 shows the scope of the data in terms of volume of data collected for the three platforms. Data type and its application in the study are shown in Table 3.

The core of the ROP Study was based on mud logging ASCII data. Foot by foot penetration rates were averaged by sliding and rotating criteria. The data was averaged over various intervals for each BHA run and was plotted ROP versus measured depth (MD), similar to that shown in Figure 1. When processing the ASCII data, torque or RPM was used as a discriminant to determine whether the BHA was being rotated or slid. This data was averaged over 5, 20, and 100 foot intervals, and averaged for the entire BHA run footage.

In almost every case, the relationship between ROP versus depth tended to follow a power law type of decay that could be represented by:

$$\textit{ROP} = k \times (\textit{DEPTH})^{-n} \qquad (2)$$

Where k and n (decay factor) are power law constants for a given set of conditions. Obviously, this relationship could be better determined by using true vertical depth (TVD) and correcting for geological factors.

This relationship should be expected since typically, formations become more difficult to drill and mechanical complications that reduce penetration rates surmount as the borehole deepens. Eventually, at certain depths, the difficulties associated with drilling deeper will affect all drilling parameters and approach some limit for these parameters. The rate of decay of penetration rate shown on graphs generated (similar to that of Figure 1) could be used to measure the loss of mechanical efficiency and natural inability to drill formations with depth.

In addition to the ASCII drilling data, Bit and BHA run summaries were evaluated (from the daily drilling reports and directional drilling reports). Overall run ROPs (total footage divided by total on bottom hours) were compared with the foot by foot ASCII data. Sliding and rotating ROPs recorded in the directional drilling reports were also compared with the electronic data.

There is sometimes ambiguity as to when an MWD or motor failure has occurred. In some instances a trip is made for lack of MWD data, and later the run may not be classified as an MWD failure. Please refer to the notes below for clarification of failure modes.

- An ***MWD Failure*** is when any of the vital sensors[1] stop transmitting data[2] to surface in real time. If a trip was made for the lack of real-time data (unless it was later discovered that a surface problem existed), it was considered an MWD failure.

- ***FE (Formation Evaluation) Failure*** is usually associated with LWD equipment or some formation measurement. When a sensor or part of the service has failed, it is considered an FE failure.

- ***Motor Failures*** have to satisfy the following conditions:

    1. Must be considered a failure by the motor company.
    2. A trip must be necessary.
    3. Unable to drill further, usually due to unsuitable stand pipe pressure.
    4. Tool needed major repairs after pulling out of the hole.

- ***Catastrophic Failures*** occur when a BHA element fractures or parts in-two down hole and basically is non-repairable at the point at which it breaks. These failures usually require a fishing job and results in several lost days and equipment.

Thrusting Devices & Penetration Rates

For the ROP Study, it was decided to use the ROP versus depth curves similar to those shown in Figure 1. Several of these were generated using data for differing conditions such as different mud types or different bit types. In most cases, (using Microsoft Excel's plotting function) the curves that represented BHAs that included a thrusting device showed higher ROP trends (similar to that shown in Figure 1).

[1] Vital Sensors are those MWD sensors that are vital enough to warrant a trip when they fail (although the decision to trip may sometimes be delayed/cancelled when a vital sensor has failed). These may be basic FE sensors – Gamma Ray, Multiple Resistivity measurements, Directional sensors (tool face and surveys) and LWD sensors (porosity measurements).

[2] Either that sensors/instrumentation fails down hole or there is a general telemetry failure. Usually that data has to be reacquired by ream logging on a subsequent run.

To evaluate ROP performance, the four scenarios shown in Table 4 were evaluated for varying intervals. Note that there are two pairs of curves in Figure 1, the sliding pair with and without the thrusting device, and the rotating pair with and without the thrusting device. For large data populations, long intervals were averaged. These intervals were 500 to 1,000 feet long and were plotted like the plot shown in Figure 1, with ROP versus Measured Depth. This data was sorted and separated according to BHA run and hole size. During the study, factors like mud types, bit types, hole angle and other factors that influence ROP were considered and plotted for the given scenarios. Where sufficient data points were available, the plots showed similar trends as in Figure 1.

For the purpose of this paper and to be as comprehensive as possible, all the data collected was used to generate the composite chart shown in Figure 1. Data was averaged according to a maximum of 1,000 feet intervals and truncated by the BHA run. Microsoft Excel's curve fitting function was used to generate the curves shown. Since the data population was quite large (data associated with 162,000 feet of drilled hole), one can be reasonably confident in drawing conclusions since spurious data likely to skew the results will be averaged into the large population.

The curves plotted in Figure 1 show that beyond 6,000 to 7,000 feet, separation starts to develop between the two pairs of curves with separation increasing with depth. This separation implies improved penetration rates where the thrusting device is used. This response was expected as the thrusting device is placed and optimized to respond to parameters and conditions at about 8,000 to 10,000 feet, which is where problems are normally experienced, i.e. getting constant weight on bit and other factors that affect the application. One observation that was not really anticipated was the generally improved response in the "all rotary" mode of drilling. ROP showed improvement in the rotary mode, although not as significant when compared to the all-sliding mode data.

To quantify the benefits, the power law equations similar to the one given in equation (1) were formulated (using Microsoft Excel) and used to calculate time to drill similar sections of hole. Various scenarios from which the cost could be derived were evaluated. This technique showed that at 10,000 feet, the penetration rates were approximately 35% and 15% higher with thrusting device BHAs for sliding and rotating respectively. An analysis was done based on percentage of sliding, typical of the intervals from 6,000 to 11,000 feet, and based on the ROP averages for the wells under consideration. It was found that the savings per hole section was on the order of $60,000 to $110,000 USD based on ROP improvement alone. These savings were more pronounced in wells with extended build sections (during the heel section of horizontal wells).

Thrusting Devices & Down Hole Tool Failure Rates

Tool failure data was collected from MWD and directional drilling final well reports. Daily drilling reports and other data sources were used to qualify this information. (See page 3 for definitions on failures.) Initially, industry standard mean-time-between-failure (MTBF) ratings were used to compare the different failure scenarios. In addition to MWD failures, motor and catastrophic failures were looked at. They were examined in three BHA scenarios as outlined below, and are summarized in Table 5. Again, as with the ROP Study, the DTF Study ignored runs where no drilling took place regardless of whether a failure occurred or thrusting device was run. Figures 2 to 5 illustrate the failure comparisons. These charts normalize failures according to circulating hours, footage drilled or runs. It should be emphasized that the drilling conditions, equipment used, MWD/PDM types and geological conditions for all these projects are quite similar.

This data is plotted in the following categories:

1. Failures per 10,000 feet of drilling
2. Failures per 100 circulating hours
3. MTBF
4. Footage between failures

The three BHA scenarios considered were:

1. BHAs that contained some kind of thrusting device
2. BHAs that had NO thrusting device (unprotected)
3. BHAs that had a particular type of thrusting device

The charts are quite consistent in terms of their implication, regardless of whether the data is normalized by footage, circulating hours or by runs. BHAs that had a certain thrusting device (known as Hydra-Thrust®) had on the order of a 50 to 70% reduction in failure rates when compared to those BHAs that were unprotected (no thrusting device). The composite averages for all thrusting devices run showed a 40 to 50% reduction in failure rates over unprotected BHAs.

The cost savings in situations where MWD failures have a significant impact on well costs could be the most significant benefit of using thrusting devices. In most of the MWD/PDM failures in this study, a failure almost always required a round trip that meant at least 15 hours of lost rig time. For these projects the associated cost is approximately $100,000 for a round trip.

Conclusions

This study looked at eighty-five (85) BHA runs where medium to high angle holes were drilled. Two areas of interest were researched – performance drilling based on penetration rates, and down hole tool failure rates.

The study found that considerable cost savings could be attributable to a properly placed thrusting device in the BHAs of medium to high angle application. These savings were in two separate areas:

- Average improvement of penetration rates of 35-15% while both sliding and rotating respectively; although penetration rate improvement was more pronounced with sliding.

- Reduction in down hole tool failure rates particularly with MWD/LWD and motors. It was observed that the use of thrusting devices contributed to the reduction of failures by approximately 40-50%.

Acknowledgements

The authors wish to thank the management of BP, Smith International Inc. and Trinpet for their permission to publish this paper. The authors would also like to thank William Schofield (BP), Jonathan Perry (BP), Maria Boyd (BP), Allan Contant (Trinpet), Glenn Martin (Smith International Inc.) and George McKown (Smith International Inc.) for their contributions to this paper.

References

1. Reich, M., Hoving, P.G., Makohl, F.: “Drilling Performance Improvements Using Downhole Thrusters”, SPE/IADC paper 29420, presented at SPE/IADC Drilling Conference in Amsterdam, The Netherlands, 28 February – 2 March 1995.
2. Geldof, W., Merrall, E., Kent, D., Dautel, M.: “World Record Horizontal Bit Runs in Oman”, SPE/IADC paper 57536, presented at SPE/IADC Middel East Drilling Technology Conference in Abu Dhabi, UAE, 8 – 10 November 1999.

Table 1 – Well Data Information

PARAMETER	RANGE
Depth (ft.)	4000 to 14,000
Hole Sizes (in.)	12-¼", 8-½"
Mud Types	Water / Synthetic Oil Base
Mud Wt. (p.p.g.)	9 – 13
Hole Profiles	1. Build to, and hold tangent of 25° to 70°. 2. Build to heel of horizontal well bore through possible multiple targets. 3. Hold lateral section of 1,500 to 2,000'
Formation Profile	Sedimentary clay/sand horizons similar to gulf coast. Soft and underdeveloped claystones. Fine grained sands. Similar on all wells.
Bit Types	Aggressive PDC to Detuned PDC, Motor Tricone bits.
Rig Type	Similar equipment and platform rig / crews on all projects.

Table 2 - Scope of Data Population

PARAMETER	ALL THRUSTING DEVICES	HYDRA-THRUST® THRUSTING DEVICE	NO THRUSTING DEVICE	IGNORED[3]	TOTAL
FOOTAGE	105,712	45,214	56,619	0	162,331
CIRC. HRS.	2,074	940	1,233	170	3,477
BHA RUNS	42	18	35	8	85

Table 3 – Data Types & Application

DATA	USED IN	REMARKS
Daily Drilling	DTF,ROP STUDIES	Usually a DIMS report from the well site to check events and 24 hr parameters. Chronological information.
MWD FWR	DTF STUDY	MWD tool failures recorded
DD FWR	DTF, ROP STUDIES	Down hole tool failures and drilling conditions recorded.
ML ASCII	ROP STUDY	Used for the bulk of the ROP Study. Consist of foot by foot data of ROP, WOB, RPM, GPM, TORQUE, PSI and other surface data.
BIT RUN	ROP STUDY	Overall run performance data could be calculated.

[3] Data for BHA runs that did not drill any footage were ignored – these BHAs included thrusting devices and or motors/MWD equipment but were disqualified, as their inclusion would have no useful value in the data population.

Table 4 – ROP Evaluation Scenarios

GROUP	PARAMETER	NOTES
SLIDING PAIR	ROP_{ST}	ROP sliding with Thrusting Device.
	ROP_{SN}	ROP sliding with NO Thrusting Device (or referred to as Unprotected).
ROTATING PAIR	ROP_{RT}	ROP rotating with Thrusting Device.
	ROP_{RN}	ROP rotating with NO Thrusting Device (or referred to as Unprotected)

Table 5 – Failure Summary Matrix[4]

FAILURE CATEGORY	BHA SCENARIO	MWD	MOTOR	TOTAL	CATASTROPHIC
FAIL PER 10,000 FT.	**ALL THRUSTING DEVICES**	0.76	0.47	1.23	0.28
	HYDRA-THRUST TOOL	0.44	0.44	0.88	0.00
	NO THRUSTING DEVICE	1.59	0.71	2.30	0.00
FAILURE PER 100 Circ. HR.	**ALL THRUSTING DEVICES**	0.39	0.24	0.63	0.14
	HYDRA-THRUST TOOL	0.21	0.21	0.43	0.00
	NO THRUSTING DEVICE	0.73	0.32	1.05	0.00
MEAN TIME BETWEEN FAILURE	**ALL THRUSTING DEVICES**	259	414	159	691
	HYDRA-THRUST TOOL	470	470	235	#DIV/0!
	NO THRUSTING DEVICE	137	308	94	#DIV/0!
FEET PER FAILURE	**ALL THRUSTING DEVICES**	13214	21142	8131	35237
	HYDRA-THRUST TOOL	22607	22607	11303.50	#DIV/0!
	NO THRUSTING DEVICE	6291	14154	4355.31	#DIV/0!

[4] The "DIV/0" in some fields indicate an infinite number due to zero failures for that category.

Figure 1 – General ROP vs. Depth trend for most scenarios investigated – Power Law trend.

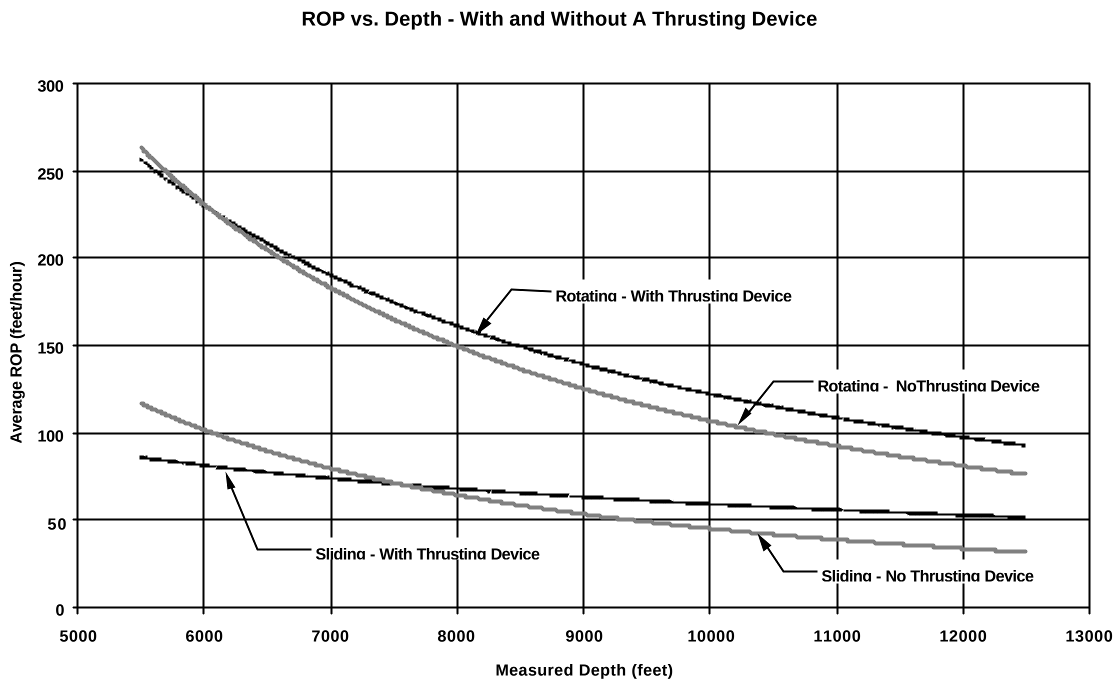

Figure 2 – Failures normalized per 10,000 feet drilled.

Note: Horizontal lines = All runs that include thrusting devices, Diagonal lines = a particular thrusting device runs only, Vertical lines = unprotected.

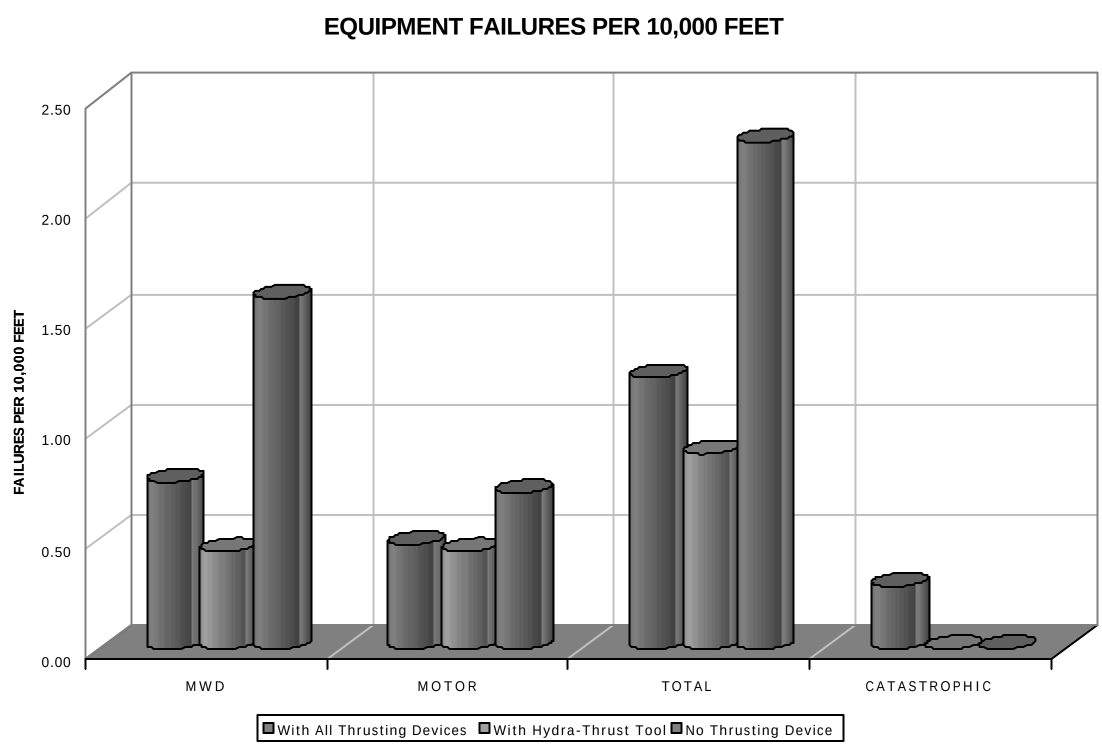

Figure 3 – Failures normalized per 100 circulating hours.

Note: Horizontal lines = All runs that include thrusting devices, Diagonal lines = a particular thrusting device runs only, Vertical lines = unprotected.

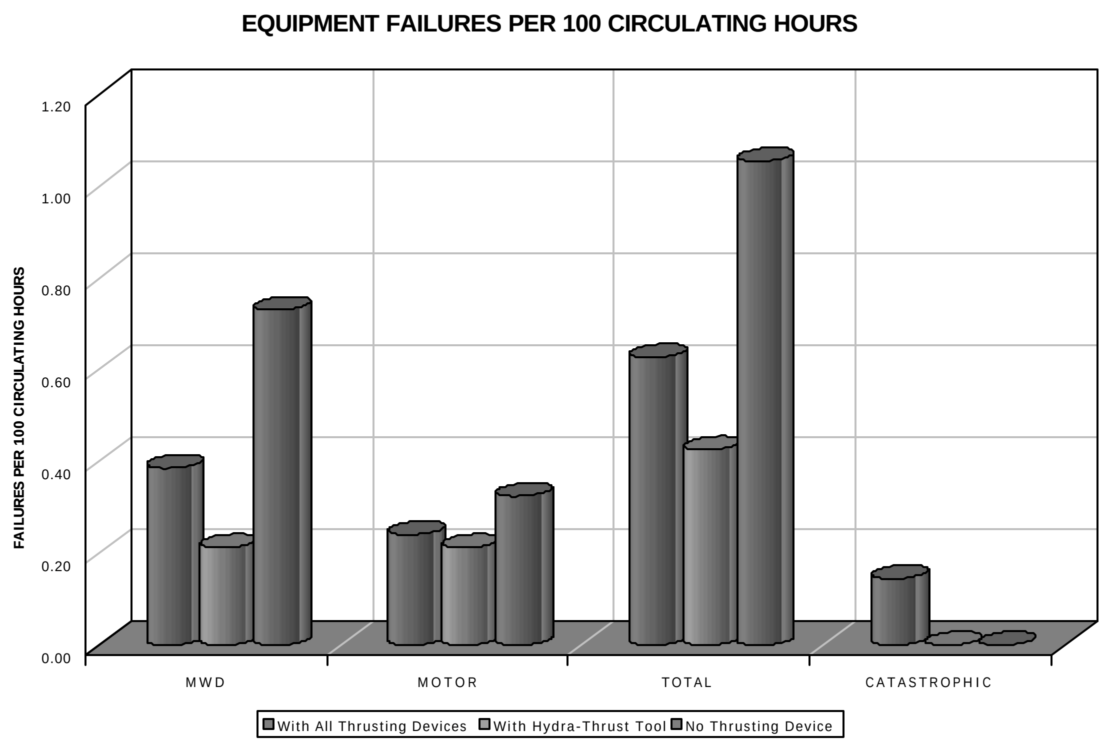

Figure 4 – MTBF – Mean Time Between Failures.

Note: Horizontal lines = All runs that include thrusting devices, Diagonal lines = a particular thrusting device runs only, Vertical lines = unprotected.

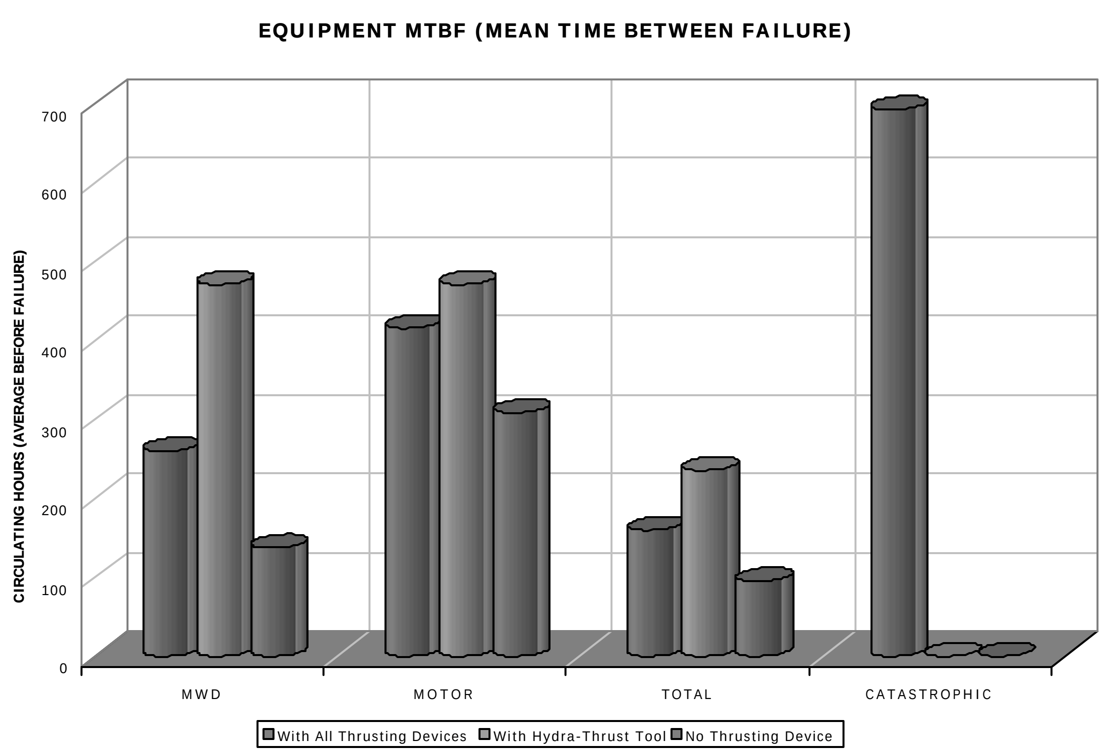

Figure 5 – Footage between failures or footage drilled before failures.

Note: Horizontal lines = All runs that include thrusting devices, Diagonal lines = a particular thrusting device runs only, Vertical lines = unprotected.